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PROTEINS IN FOODS

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PREFACE

At its annual meeting at Nagpur in December 1955, the Nutrition Advisory Committee of the Indian Council of Medical Research recommended that one of its members (Dr V. Subrahmanyan) should prepare 'a note setting out all the information on protein-rich foods not normally consumed but available in this country'. The recommendation was accepted by the Advisory Board of the Council and was conveyed to the concerned member for action. It was later felt and decided that it would be useful to have comparative data for all food materials, since this would make the review more comprehensive and valuable not only to India but also to other parts of the world.

The area in which the literature lay was extensive and scattered. The data available o[illegible] nutritive value and amino acid composition of different protein[illegible]deed massive. That these were obtained by divergent metho[illegible]at in many cases they were discordant called for extra care in their collation. The amino acid composition had been expressed differently by different workers, as for example, from 100 g. protein as basis (16 g. nitrogen, the rational thing to do) to 100 g. food as basis or amino acid nitrogen as a percentage of total nitrogen. The amino acid values for all the proteins herein listed have now been expressed uniformly on the basis of 16 g. nitrogen by recalculation of the values wherever necessary.

Under each class of foodstuff, a résumé of the more important aspects is presented, out of the survey of the entire literature on the subject. Tables are given under each chapter in two sections, one on the nutritive value and the other on the essential amino acid composition of the proteins in the foodstuffs arranged in alphabetical order. This is followed by relevant bibliography. Thus, in the present compilation, an attempt has been made to bring under one cover an extensive mass of scientific information assiduously collected by workers in several countries. No effort has been spared to make the collection as far as possible exhaustive, but it is likely that there may be some inadvertent omissions for which the authors ask to be forgiven.

In view of the importance of proteins in nutrition, it is hoped that the collected information will be of value not only to the nutrition scientist and the dietetician, but also to the average citizen in enabling

him to plan and practise his daily dietary. From this point of view, some of the less familiar foods, on the basis of analytical and nutritional data now available, deserve to be increasingly popularized and more widely used.

The authors thank the members of the Nutrition Advisory Committee of the Indian Council of Medical Research for helpful suggestions. They have had the privilege of the critical appraisal of the manuscript by Dr V. N. Patwardhan, M.Sc., Ph.D., F.N.I., Director, Nutrition Research Laboratories, Coonoor. Thanks are also due to Shri N. Chandrasekhara for technical help and to Shri K. A. Korula, Manager, Wesley Press, Mysore, for his co-operation.

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INTRODUCTION

PROTEINS are important constituents of both plant and animal cells and protoplasm in general. There is no known life process without them. While plants synthesize proteins for their needs from simple inorganic elements and compounds as are present in the soil and air, animals have to depend on ready-made proteins and their intermediates or breakdown products, as elaborated by other forms of life, for the synthesis and maintenance of their tissues; hence the importance of proteins in the diets of all animals including man.

Wide variations have been reported not only in the protein content of the dietaries of the people in different countries, but also in the ratio of animal protein to total protein in the diet. In economically advanced countries, the average intake of protein is generous and the proteins of animal origin make up nearly half the total protein. In the under-developed countries, both the total protein intake and the proportion of animal protein are very much lower. Diet surveys carried out in India have shown that the bulk of the food in Indian dietaries is formed by cereals, which supply about 80 per cent of the total energy and are the major source of dietary proteins.*

Left to themselves, people take food according to their likes, although, intuitively, it might sometimes conform to rational standards. Often it falls below these standards, because, protein-rich foods like milk, meat and eggs are not normally within the reach of the common man, specially in the under-developed countries where they are produced in insufficient quantities. Hence, he eats what best is available to him from the point of view of palate and appeasement of hunger. The question arises, then, whether he can be helped to a better nutritional status by placing before him all available knowledge on the protein content and protein quality of various food materials produced in his locality, so that he can intelligently select from among them the best possible balanced diet without much additional cost to the family budget.

Assessment of nutritive value: It was only towards the close of the last century that it was realized that the proteins in different foods have different nutritive values. Of the two methods commonly employed for the assessment of the nutritive value of dietary proteins, namely, the nitrogen balance method and the rat growth method, the former possesses the advantage of furnishing information both on the biological value and the digestibility. The rat growth method is easier to carry out and, for this reason, has been more widely used by workers in the field. The data on the nutritive value of proteins presented in this review relate mostly to the biological values and coefficients of

* Patwardhan, V. N. *Indian J. med. Sci.*, **10**, 1 (1956).

digestibility determined by the nitrogen balance method and the protein efficiency ratios (P.E.R.) determined by the rat growth method, although in a few cases values for the 'net protein utilization' as determined by the carcass nitrogen method have also been included. So far as the relative value of proteins in the nutrition of children and infants is concerned, the protein efficiency ratios should provide a far more reliable estimate in view of the fact that young growing animals are used in their evaluation.

Amino acids in proteins: Although all amino acids are essential for tissue formation and various body functions, only some of them—the so-called essential amino acids—need to be provided from exogenous supplies. In fact, the essential amino acids determine to a large extent the nutritional quality of dietary proteins; consequently, in the assessment of the nutritive value of proteins the amino acid make-up assumes the highest importance. Knowledge of the essential amino acid make-up, in addition to the amino acid requirements (data regarding which have been collected by a number of workers), makes it possible for proteins to be evaluated in terms of their ability to meet human requirements. The amino acid composition of the proteins in different materials, determined by both the classical chemical methods as well as the more recent microbiological and chromatographic methods, have been presented in this review.

Attempts have been made by different workers to predict the nutritive value of dietary proteins from their 'chemical scores' as computed from their essential amino acid composition. Although, in a number of cases, the deviations of the predicted values from the experimentally determined values are small, the agreement is still not convincing.

The inter-relationships among certain amino acids and between certain amino acids and vitamins are important. Cystine has a sparing action on methionine, while tyrosine has a sparing action on phenylalanine. The requirements of tryptophan are enhanced when nicotinic acid is not sufficient to meet the body's needs. Vitamin B_{12} has a sparing effect on both methionine and choline.

The amino acid composition of a protein by itself cannot, however, give a complete picture of its nutritive value in view of such factors as amino acid imbalance and amino acid availability.

Amino acid imbalance: The absence of any one essential amino acid in a dietary protein produces negative nitrogen balance. Not only should a dietary protein contain adequate amounts of the essential amino acids, but these must also be present, as far as possible, in balanced proportions. For example, the requirements of tryptophan are enhanced in the presence of large quantities of threonine and phenylalanine in the dietary protein; therefore, if a protein contains unusually large amounts of threonine and phenylalanine, but is marginal

in tryptophan, the risk of tryptophan deficiency would be far greater than if the protein contains only moderate amounts of these two amino acids.

Amino acid availability: *In vitro* digestion studies with proteins indicate that amino acids are liberated from different proteins at different rates characteristic of the amino acid or its linkage or sequence in the protein. It is well to remember that incomplete digestion and absorption may make a difference in the effective amino acid composition of a dietary protein. As for biological availability, all essential amino acids have been reported to be completely available from certain proteins, such as roast beef protein, while wide variations occur in their availability from certain others, such as cottonseed protein.

Absorption of the end products of digestion: The end products of protein digestion need not necessarily be amino acids; they may also be larger molecules of the nature of peptides. In the appraisal of the nutritive value of proteins, it would be proper to take into account, besides the amino acid composition, the types of peptides formed physiologically.

Time Factor: Maintenance, as well as growth, is dependent on the simultaneous presence of all the essential amino acids in the breakdown products of protein digestion. This is demonstrated by the fact that animals fed a basal diet in which the sole source of nitrogen is an appropriate mixture of all the essential amino acids excepting one which they receive as a delayed supplement, lose weight as rapidly as the controls. Time differences in the gastro-intestinal enzymatic liberation of amino acids would also be a factor in the effective utilization of certain dietary proteins.

The practical significance of the time factor *vis-à-vis* protein utilization lies in the fact that a proper distribution of dietary protein, both as regards quality and quantity, among the different meals is desirable from the point of view of optimal nutrition.

Influence of processing on the nutritive value of proteins: Certain classes of foodstuffs, especially some of the legumes, improve in protein value as a result of heat-processing, either through inactivation of trypsin inhibitors or through increase in the availability of certain amino acids, particularly the sulphur-containing ones. Conversely, processing also adversely affects the nutritive value of the proteins present in certain other classes of foodstuffs, either by destroying or altering certain amino acids or by altering the protein so that it becomes resistant to the action of digestive enzymes or by retarding the rate of release of individual essential amino acids in the intestinal tract.

Protein requirement: Optimum protein requirement is a subject of much speculation and controversy. Although various national and international organizations have put out tables of protein requirements

and protein allowances, they have not been included in the present review because of lack of unanimity in these values.

The requirement of dietary protein is determined to a large extent by its quality; it is naturally greater in the case of proteins of low nutritive value. On body weight basis, the requirement is also enhanced in the case of infants and children and in times of physiological stress such as pregnancy, lactation and convalescence.

It has been reckoned that 10 to 14 per cent of the calories in the diets of populations in economically advanced countries is contributed by protein. The Committee on Nutrition of the British Medical Association has recommended that a protein allowance yielding 14 per cent of the total calories is desirable for infants, children, adolescents, and pregnant and nursing women, while an amount corresponding to 11 per cent of the total calories should suffice for the needs of ordinary adults other than those engaged in heavy manual work. This level of protein calories is not likely to be reached in diets based predominantly on cereals and tubers, particularly the latter which are consumed by large sections of the population in certain under-developed regions.

Animal and vegetable proteins: Although the differences in biological value for maintenance between vegetable and animal proteins are not great, the growth promoting value (P.E.R.) of vegetable proteins has been reported, in most cases, to be less than half that of animal proteins such as those present in eggs, milk, meat or fish. Thus the dietary proteins of vegetable origin are not ideally suited to meet the needs of the growing child. In under-developed countries, infants, on weaning, are faced with a sudden change from a diet based exclusively on human milk to one which is a prototype of the adult ration, practically devoid of any milk or other sources of animal protein. This, in addition to the lack of sufficient calories in their food, leads to widespread protein malnutrition in late infancy and early childhood.

The superiority of animal proteins over proteins of vegetable origin is mainly due to the presence of the essential amino acids (especially methionine, tryptophan and lysine) in larger amounts and also in better balanced proportions. It is a moot point whether a certain proportion of animal protein in the diet is indispensable for optimal nutrition. Races which consume relatively large quantities of milk, meat, fish and eggs are known to be of better physique and generally healthier than races which subsist largely, if not exclusively, on foods of vegetable origin. It must, however, be borne in mind that other factors, such as the intake of total protein, minerals and vitamins, as well as climate and heredity are also to be reckoned with.

Supplementary relationships: There is plentiful evidence in the literature to show that two or more proteins of vegetable origin can be so blended that their amino acid deficiencies are mutually made up, with

the result that the mixture contains proteins of superior nutritive value.

In actual practice, no single foodstuff is consumed exclusively as the sole article of diet. There is always some supplementation and, generally, the risk of protein deficiency arises from the following directions (*a*) inadequacy of quantity; (*b*) improper balancing; (*c*) inefficiency in utilization; and (*d*) secondary effects of associated components. If the supplement is of the right type and is, in addition, in a concentrated form and free from toxic factors, suitable blends of vegetable proteins should be practically as good as animal proteins.

Survey of protein-rich materials: There is world-wide interest in the survey of low-cost protein-rich foods with a view to finding ways and means of improving the diets of vast populations suffering from protein malnutrition. A large volume of data has accumulated on the nutritive value and amino acid composition of the proteins in staple and other foods in different parts of the world and on the supplementary relationships among some of them.

The importance of the evaluation of the nutritive value of the proteins in various little-known foods is being increasingly realized. Some of these contain proteins of high biological value and their cultivation can be extended with profit to different parts of the world. The potentialities of protein-rich materials, which are not at present commonly used as human food, also need to be assessed. Examples of such unconventional protein-rich foods are oilseed cakes, cereal bran and fish meal. These may not be by themselves in a condition suitable for human consumption; they will require purification and/or processing by comparatively simple and inexpensive methods.

The present survey covers not only the unconventional and the little-known foods, but also the common ones, because it is only by comparison with the proteins of the latter that a useful appraisal of the protein value of the former can be made. Specific analytical data on dietary proteins have been published sporadically and lie scattered in the literature. The food tables that have been constructed in different countries are only a partial help to the solution of the larger problem of balanced protein nutrition. While the overall analyses given in these conventional tables suffice to choose foods for providing sufficient calories, vitamins and minerals, they are not sufficiently informative on protein quality, which, so far as protein is concerned, is of paramount importance. The purpose of this monograph is mainly to fill this gap and focus attention on the salient features of the proteins present in different classes of foodstuffs.

CHAPTER I

CEREALS

CEREALS are predominantly sources of carbohydrates and form the staple diet of a large section of the world's population as the main supplier of calories. Some regions depend almost exclusively on any one cereal while others use mixtures. Thus, wheat (*Triticum aestivum*) contributes anything up to 50 per cent of the total calories depending on the region[1, 2]. Rice (*Oryza sativa*) is the staple cereal consumed by more than half the world's population and is the chief source of calories in Asiatic diets.[3] Protein, though proportionately low in cereals, is still a very important factor in adjudging the overall nutritive quality; this is of special significance in the case of corn (*Zea mays*) diets[4, 5, 6]. Availability of the proteins in certain cereals is an equally important consideration[7]. In the case of coarse grains, as also those from which the seed coat cannot be easily removed, the digestibility of protein is of a low order[8]. It has been suggested that their acceptability as human food can be enhanced by suitable processing[9]. Improvement of the nutritive value of cereal proteins by supplementation with the limiting amino acids[10] or small amounts of foods containing high quality protein[11] has also been advocated.

Protein content: The protein content of cereals and cereal bye-products has been presented in Tables I and II and the list includes quite a few unfamiliar cereals like Deccan grass grains[12] (*Punicum crus-galli var. frumentaceum*), wild rice[13] (*Zizania aquatica*), Rājkeera[14, 15] (*Amaranthus paniculatus*), bamboo seeds[16] (*Bambusa arundinacea*), Quinoa[17, 18] (*Chenopodium quinoa*) and Canihua[17, 19] (*Chenopodium pallidiculae*). Both the protein content and the protein quality in different cereals are influenced by a number of factors, such as those determined by genetics[20-22], environment[23] and variety[24-26]. A hybrid tetraploid sample of rice has recently been reported to contain as much as 13.3 per cent protein[27]. By crop selection, a millet has been produced in China which contains over 14 per cent protein instead of the usual 9 per cent[28]. On the other hand, the protein content of certain varieties of ragi (*Eleucine coracana*) is as low as 3.5-4.0 per cent.[29-31]

Amino acid composition: The amino acid composition of the proteins of rice[29-32], wheat[29-31, 33], ragi[29-31], jowar[29-31] (*Sorghum vulgare*), barley[33] (*Hordeum vulgare*), oats[33-35] (*Avena sterilis*), corn[36, 37] and of the products of their milling has been exhaustively investigated (Table II). Rice[38], wheat[39] and corn[30] proteins are all deficient in lysine, but evidence is conflicting as to whether oats protein[39, 40] also is deficient in this amino acid. In addition, rice protein

is deficient in threonine[41] and wheat protein, in valine[42], while corn protein is deficient in tryptophan[43, 44] and also in threonine[44] and methionine[44]. Corn gluten meal is reported to be deficient in arginine, lysine and tryptophan[45]. The marked amino acid imbalance of zein is due to the presence of glutamic acid, leucine, alanine, proline and phenylalanine in relatively large amounts[46].

The essential amino acids in several cooked and uncooked Mexican cereal foods have been determined[47]. The proteins of Quinoa and, to a lesser extent, Canihua are well balanced with respect to all the essential amino acids[17]. The proteins of Rajkeera have been found to contain a high proportion of lysine by microbiological assay[15], but this could not be confirmed using the technique of chromatography[48].

Besides actual contents, availability of amino acids in wheat flour[49] and zein[50] have also been studied. While the availability of all the essential amino acids from wheat protein is relatively high, ranging from 92 per cent for threonine to 99 per cent for histidine[49], the availability of valine from zein is of a low order[50].

Nutritive value: Complete data on the biological value of cereal proteins in general[51] and of wheat[52-54], corn[55-57] and rice[58] proteins in particular, are available (Table I). The relative nutritive values of different cereal proteins have been compared[59]. Rice proteins possess a far higher growth-promoting value than wheat proteins[60, 61] and also a higher biological value than other cereal proteins[62]. While the proteins of 'Aman' rice promote good growth in rats[63] and are highly digestible,[64] the proteins of 'Aus' rice do not possess any growth-promoting value[63] and their digestibility is also of a lower order[64]. As sources of dietary proteins Quinoa[17, 18] and Canihua[17] deserve special mention because the proteins of the former are reported to excel and those of the latter to equal milk proteins in nutritive value. Acid hydrolysed zein, in contrast to enzyme hydrolysed zein, promotes growth in rats[65]. Corn of high protein content has been found to contain larger proportions of zein and to be nutritionally poorer than corn of low protein content[23, 66, 67].

Processing: The effect of heat-processing on the nutritive value of cereal proteins has been reviewed[68]. The deleterious effect of heat on cereal proteins is very profound and this is an important consideration in the manufacture of processed cereals like corn flakes[69]. Even shredding has been noted to lower the nutritive value of wheat protein[70]. Inactivation of lysine during bread making has assumed considerable practical importance[71]. The influence of certain treatments like parching, beating and parboiling on the nutritive value of the proteins in some cereals and millets has been investigated[63, 72]. The effect of polishing rice[59, 62, 73] and milling wheat[62, 74, 75] and corn[62] and rye[62] (*Secale cereale*) on the nutritive value of their proteins has also been determined.

Supplementary value: The supplementation or enrichment of different cereals has been studied by a number of workers. Both defatted corn germ[76, 77] and wheat germ[77-79] effectively improve the nutritive value of wheat flour; corn germ protein is, however, inferior to wheat germ protein in its supplementary value to wheat proteins[80]. Proteins of milled rice have been reported to possess a phenomenal supplementary value to the proteins of milled wheat flour and milled white corn meal[81]. Buckwheat (*Fagopyrum esculentum*) proteins supplement the proteins of wheat, corn and rye[82]. It has been shown by human metabolism studies that replacement of part of the wheat in poor vegetarian diets by barley, corn, ragi or bajra (*Pennisetum typhoideum*) brings about an improvement in the overall biological value of the proteins in the cereal mixture[83].

Fortification: Fortification of bread with lysine[84] but not with cystine[85] increases the biological value of its proteins. The proteins of milled and processed milled rice are improved by the addition of lysine, threonine and methionine and the proteins of enriched milled hard wheat flour, by the addition of lysine, threonine, valine (and vitamin B_{12})[86].

Bye-Products

Important cereal bye-products are the germ, the polishings and the bran. The isolation and utilisation of proteins from these sources in human dietaries have considerable possibilities. The utilisation of germ is complicated by association with a considerable proportion of highly unstable fat and that of bran and polishings, by the presence of fair amounts of phytin and fibre.

Germ: Wheat germ represents 1.5 per cent by weight of the whole wheat kernel and is an exceptionally valuable package of nutrients including proteins of high biological value[87]. Wheat germ, processed by steam or with ethylene-dichloride vapour followed by steam, is highly palatable with excellent baking and keeping qualities, in contrast to raw wheat germ which develops off flavours during storage[88]. Commercial wheat germ has an average protein content of 29 per cent[89]. Wheat germ has been successfully used in bread making and enhances its nutritive value[90, 91]. The high biological value of wheat germ protein is not impaired by such heat processing as is necessary to make it suitable for human consumption[92]. Its protein efficiency ratio is less than that of egg[93], but is equal to that of skim milk powder and higher than that of casein[94]. The merits[95, 96] and demerits[96] of wheat germ as a food additive have been discussed.

Defatted corn germ contains 21 per cent protein and is a valuable protein food[97]. Corn germ protein also possesses a high nutritive value[98], but is slightly inferior to wheat germ protein[80, 94, 99]. At 10 per

cent level, corn germ protein is 85 per cent as digestible as beef protein and possesses equivalent biological value for the growing rat[97].

Rice germ is reported to contain 20 per cent protein[100]. The amino acid composition of rice germ protein has been determined microbiologically[101]. Rice germ protein is reported to possess a high biological value and to supplement the proteins of polished rice[101].

Polishings and bran: The nutritive value of the proteins of rice polishings is a subject of controversy. According to Kik[73], the proteins of rice polishings and rice bran possess a higher biological value but lower digestibility than the proteins of milled rice; while the growth-promoting value of the proteins of rice polishings is of the same order as that of whole rice proteins, that of rice bran proteins is slightly less. On the other hand, work carried out in India has shown that the proteins of rice polishings do not at all support growth in rats[63].

The protein content of rice bran has been found to be particularly high[102]. Methods for the preparation of refined rice bran suitable for human consumption have been described[100, 103], as also an attempt to process wheat bran for human consumption by soaking, steaming, frying and fermenting[104]. Mechanical pulverization increases the extent of utilisation of wheat bran proteins[105, 106]. It is further reported that continuous ingestion of bran has no deleterious effect on human beings[107].

As concentrates, both wheat bran and rice bran are inferior in nutritive value to sardine (*Sardinella fimbriata*) cake[108], soya bean (*Glycine Max. Merr*) cake[103], rape seed (*Brassica napus*) cake[108] and sesame (*Sesamum indicum*) cake[108], but rice bran is superior to corn meal[109] or groundnut meal[109] (*Arachis hypogea*).

TABLE I

NUTRITIVE VALUE OF CEREAL PROTEINS

SOURCE	Protein content: N × 6.25 %	Level of feeding %	Nutritive Value: Biological value %	Nutritive Value: Coefficient of true digestibility %	Nutritive Value: Protein efficiency ratio
Bajra or Cambu (*Pennisetum typhoideum*)[110] ...	9·6	10	...	...	1·8
Bajra[111] ...	10·5	5	83·0	89·0	...
Bajra[112] ...	10·0	5	...	...	1·2
Bajra[113] ...	10·7	10	...	...	1·4
Bamboo seeds (*Bambusa arundinacea*)[16] ...	12·0	10	74·4	90·1	2·0
Barley, whole (*Hordeum vulgare*)[114] ...	12·4	5	...	...	0·6
		7	...	...	1·2
		8	...	...	1·3
Barley, whole, ground[115] ...	...	10	64·0	...	...
Barley, whole, ground[116] ...	...	...	77·0	89·0	...
Barley, pearled[59] ...	9·2	5	...	...	1·6
		8	...	...	1·7
Barley, meal[117] ...	9·8	9	...	...	2·0
Buckwheat from El Salvador (*Fagopyrum esculentum*)[82] ...	9·2	5	...	...	2·1
		7	...	...	2·1
Buckwheat, whole from Wisconsin[82] ...	9·2	5	...	...	2·1
		7	...	...	2·0
		8	...	...	2·0
Buckwheat, whole, groats[117]	13·7	8	...	...	2·5
		13	...	...	2·1
Buckwheat, fine meal[117] ...	4·9	4	...	...	3·0
Buckwheat flour, from Wisconsin[82] ...	10·2	5	...	...	1·7
		7	...	...	1·8
		8	...	...	2·1
Corn or Maize, whole (*Zea mays*)[62] ...	...	5	84·7	93·0	...
Corn, whole[72] ...	...	6	60·1	80·3	...
Corn, whole[118] ...	...	8	...	...	0·8
Corn, whole[119] ...	...	5	84·0	...	...
		8	67·0	...	...
Corn, whole[120] ...	...	...	64·9	92·1	...
Corn, whole[121] ...	...	10	49·0	93·0	...
Corn, whole[122] ...	...	10	...	...	1·5
Corn, whole, white[123] ...	8·4	9	...	...	1·3
Corn, whole, white[124] ...	...	8	76·0	...	...
Corn, whole, yellow[44] ...	8·9	8	...	...	1·2
Corn, whole, yellow[59] ...	9·2	5	...	...	1·4
		8	...	...	1·6

TABLE I. *Nutritive Value of Cereal Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Corn, whole, yellow[114] ...	8·9	5	...	...	0·5
		7	...	...	0·9
Corn, whole, yellow[123] ...	9·3-9·8	10	...	...	1·3
Corn, whole, yellow[124] ...	...	8	67·0	...	...
Corn, whole, yellow[125] ...	...	12	...	...	1·2
Corn, whole, low protein[23]	7·3	6	68·6	88·3	...
Corn, whole, low protein[23]	9·2	8	56·8	93·1	...
Corn, whole, high protein[23]	10·7	6	63·1	92·5	...
Corn, whole, high protein[23]	13·4	10	46·9	94·8	...
Corn, whole, high protein[23]	20·0	10	44·7	95·3	...
Corn, whole, high protein[23]	21·1	8	49·2	95·4	...
Corn, whole, stored for 8 months[120] ...	...	...	57·7	91·7	...
Corn, whole, ground and stored for 8 months[120] ...	...	...	58·6	91·3	...
Corn, whole, stored for 24 months[122] ...	...	10	...	...	1·3
Corn, yellow, cooked[123] ...	...	10	...	...	1·4
Corn, milled[62] ...	...	5	36·2	88·5	...
Corn, parched[72] ...	...	6	63·9	80·8	...
Corn, toasted[125] ...	...	12	...	...	0·8
Corn flakes, toasted[126] ...	6·2	5	...	...	—ve
Corn endosperm[119, 127] ...	...	3	88·0	...	...
		7	70·0	...	...
Corn endosperm (waxy)[128]...	11·0	5	54·5	92·5	...
Corn endosperm (starchy)[128]	10·8	5	57·0	93·5	...
Corn meal, whole[109] ...	...	9	...	...	1·2
Corn meal, whole[129] ...	...	6	...	...	0·5
		8	...	...	1·2
Corn meal, whole[130] ...	...	8	...	...	1·2
Corn meal, whole, stored for 24 months[122] ...	...	10	...	...	1·3; 1·4
Corn meal, white, milled[81]	7·7	6	...	...	0·5
Corn meal, white, milled[82]	...	6	...	...	0·2
Corn oil meal[80] ...	24·0	10	...	...	2·6
Corn germ[94] ...	21·3	10	...	...	2·1
		15	...	...	1·6
		18	...	...	1·3
Corn germ[97] ...	21·2	10	77·6	85·0	...
Corn germ[119] ...	...	7	70·0	...	...
Corn germ[131] ...	23·2	10	...	...	2·0
Corn germ from waxy Corn[128] ...	25·2	5	69·5	84·0	...
Corn germ from starchy corn[128] ...	24·8	5	68·0	80·5	...
Corn germ meal, hot-expelled[57] ...	25·3	5	66·0	70·0	...
Corn germ meal, hot-expelled[98] ...	18·1	10	...	...	2·1

—ve denotes negative growth.

TABLE I. *Nutritive Value of Cereal Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Nutritive Value: Coefficient of true digestibility %	Nutritive Value: Protein efficiency ratio
Corn germ meal, ether-extracted[98] ...	22·5	10	...	...	1·8
Corn germ meal, ether-extracted, fresh[57] ...	20·8	5	83·0	72·0	...
Corn germ meal, ether-extracted, stored at room temperature for 2 years[57]	20·8	5	79·0	81·0	...
Corn germ meal, ether-extracted, stored at room temperature for 6 years[57]	20·8	5	55·0	76·0	...
Corn gluten, commercial[80]	47·1	10	...	...	0·7
Corn gluten from white corn[123] ...	41·5	15 23	... ...	... ...	1·0 0·7
Corn gluten from yellow corn[123] ...	27·0	13 18 23	... ...	... ...	0·7 0·8 0·8
Corn gluten from waxy corn[128] ...	...	5	44·0	95·0	...
Corn steep-water concentrate[57] ...	27·1	6	35·0	88·0	...
Grain Sorghum (*Sorghum vulgare*)[114] ...	10·1	7 8	... ...	... ...	0·2 0·4
Grain Sorghum from Arkansas[82] ...	...	8	...	...	0·4
Jowar or Cholam (*Sorghum vulgare*)[72] ...	...	6	83·1	91·4	...
Jowar[110] ...	8·2	10	...	...	2·0
Jowar[111] ...	10·3	5	83·0	91·0	...
Jowar[112] ...	9·9	5	...	...	0·8
Jowar[132] ...	...	5 8	... ...	... ...	0·2 1·2
Jowar, parched[72] ...	...	6	90·9	92·7	...
Kaoliang (*Sorghum vulgare*)[115] ...	...	...	56·0	...	...
Kaoliang[133] ...	...	10	...	...	1·0
Millet (*Panicum miliaceum*)[134] ...	...	10	56·0	91·0	1·2
Millet meal[117] ...	13·4	8 13	... ...	... ...	1·0 0·9
Oats, whole (*Avena sterilis*)[116] ...	...	...	83·0	95·0	...
Oats, rolled[59] ...	14·9	5 8 10 12	... ...	... ...	2·2 2·1 2·5 2·3

TABLE I. *Nutritive Value of Cereal Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Oats, rolled[61] ...	...	6	...	...	2·1
Oats, rolled[62] ...	...	5	82·1	92·1	...
Oats, rolled[114] ...	14.9	7	...	...	1·6
		8	...	...	1·7
		10	...	...	1·6
		12	...	...	1·6
Oats, rolled[117] ...	17·4	4	...	...	1·6
		8	...	...	2·2
		16	...	...	1·7
Oats, rolled[135] ...	...	...	66·0	92·0	...
Oats, rolled[136] ...	...	10	...	...	1·5
Oats, puffed[136] ...	...	10	...	...	0·3
Oats, pre-cooked[137] ...	16·1	5	98·0*	93·8*	...
Oats, drum-dried[136] ...	...	10	...	...	1·6
Oats, oven-expanded[126] ...	...	10	...	...	1·6
'Quick' oats[126] ...	...	5	...	...	1·7
		8	...	...	1·7
		10	...	...	1·6
Oat flour 'Cheerios'[126] ...	14·9	10	...	...	1·1
Quinoa (*Chenopodium quinoa*)[17] ...	11·0	6	...	...	1·7
		9	...	...	1·6
Ragi (*Eleucine coracana*)[72] ...	...	6	89·9	92·6	...
Ragi[111] ...	7·1	5	89·0	80·0	...
Ragi[112] ...	7·4	5	...	...	0·7
Ragi[132] ...	...	5	...	...	1·0
Ragi[138] ...	8·3	5	90·5	77·5	...
Ragi, parched[72] ...	...	6	93·9	88·6	...
Rajkeera, raw (*Amaranthus paniculatus*)[14] ...	14.5-16·0	10	73•7	80·4	2·1
Rajkeera, puffed[14] ...	...	10	...	...	1·9
Rala or Italian millet (*Setaria italica*)[139] ...	10·0	5	77·0	91·0	...
Rice (*Oryza sativa*)[110] ...	...	10	...	...	2·0
Rice[115] ...	...	10	77·0	...	...
Rice, whole[58] ...	7·5	6·0	72·7	96·5	1·8
Rice, whole[62] ...	...	5	85·1	94·1	...
Rice, brown[59] ...	9·0	5	...	...	1·9
		8	...	...	2·3
Rice, milled[62] ...	...	5	79·0	95·1	...
Rice, polished[41] ...	...	5	...	...	1·0
Rice, polished[58] ...	6·5	6	66·6	98·0	1·7
Rice, polished[59] ...	5·2	5	...	...	2·2
Rice, polished[60] ...	6·5	6	...	...	1·9
Rice, polished[61] ...	...	6	...	...	2·2
Rice, polished[72] ...	...	6	80·3	93·6	...
Rice, polished[86] ...	6·2	5	...	...	1·9
Rice, polished[101] ...	6·6	6	61·4	96·9	1·8

* determined by human metabolism experiments.

TABLE I. *Nutritive Value of Cereal Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Rice, polished[111] ...	6·9	5	80·0	97·0	...
Rice, polished[112] ...	6·3	5	...	...	1·7
Rice, polished[117] ...	8·0	8	...	...	1·7
Rice, polished[118] ...	...	6	...	...	2·0
Rice, polished[125] ...	...	9	...	...	1·4
Rice, polished[132] ...	...	5	...	...	1·3
Rice, polished[140] ...	...	6	...	...	1·7
Rice, (polished) protein-extracted[58] ...	16·7	9	66·2	78·3	...
Rice, polished, strain 661 (Coimbatore Sanna)[141] ...	5·7	5	...	...	2·0
Rice, polished, strain 1092 (Bangara Sanna)[141] ...	6·9	5	...	...	2·2
Rice, polished, strain 749 (Ratna Chudi)[141] ...	5·6	5	...	...	2·2
Rice, polished, strain 139 (Mysore Kaddi)[141] ...	7·1	5	...	...	2·1
Rice, polished, var. Dhairal (Aus)[63] ...	6·3	5	80·0	94·7	—ve
Rice, polished, var. Bhasamanik (Aman)[63] ...	7·1	5	80·0	97·2	2·1
Rice, parboiled and polished, var. Bhasamanik (Aman)[63] ...	...	5	80·0	94·4	...
Rice parboiled and hand-pounded[83] ...	...	...	66·6*	81·0*	...
Rice, puffed[125] ...	...	10	...	...	0·6
Rice, processed, milled ('Minute Rice')[86] ...	7·7	5	...	...	1·7
Paddy, parboiled[72] ...	...	6	86·5	92·6	...
Paddy, parched, parboiled ('Kurmura')[72] ...	...	6	90·7	94·7	...
Paddy, parched ('Lohi')[72] ...	...	6	82·3	96·9	...
Paddy, beaten ('Pohe')[72] ...	...	6	87·6	93·4	...
Paddy, beaten, parched ('Murmura')[72] ...	...	6	80·4	96·9	...
Rice bran[58] ...	12·3	5	84·9	77·6	...
		8	71·9	83·0	1·5
Rice bran[109] ...	...	9	...	...	1.5
Rice polishing[58] ...	12·7	5	82·9	91·3	...
		8	78·9	88·7	1·8
Polishing from raw rice var. Dhairal (Aus)[63] ...	11·2	5	68·0	62·6	—ve
Polishings from raw rice, var. Bhasamanik (Aman)[63]	13·2	5	69·0	77·8	—ve
Polishings from parboiled rice, var. Bhasamanik ('Aman')[63] ...	...	7	58·0	...	...

—ve denotes negative growth.

* determined by human metabolism experiments.

TABLE I. *Nutritive Value of Cereal Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Nutritive Value: Coefficient of true digestibility %	Nutritive Value: Protein efficiency ratio
Rice germ[101] ...	14·9	6 9	78·1 ...	86·9 ...	2·6 1·9
Rye, whole (*Secale cereale*)[59]	11·0	5 8 10	... ...	... ...	2·3 2·2 1·8
Rye, whole[62] ...	...	5	80·4	91·0	...
Rye, whole[114] ...	10·5	5 7 8 9	... ...	... ...	2·0 1·9 1·4 1·5
Rye flour, whole[142] ...	9·4	5 8 9	... ...	... ...	2·0 1·4; 1·6 1·5
Rye, milled[62] ...	...	5	69·7	90·5	...
Rye flour, milled[82] ...	7·5	6	...	...	0·8
Rye bread[143] ...	...	5	66·0	...	...
Rye bread[144] ...	9·9	10	...	...	1·3
Rye bread from 70% extraction flour[144] ...	6·6	6	...	...	1·3
Rye bread from 70% extraction flour[145] ...	7·4	7	...	...	1·1
Rye bread crust[144] ...	6·6	6	...	...	0·8
Rye bread crumb[144] ...	7·0	7	...	...	1·3
Rye-oat-corn mixture, raw[136] ...	...	10	...	...	1·5
Rye-oat-corn mixture, gun-exploded[136] ...	...	10	...	...	0·5
Wheat, whole (*Triticum aestivum*)[52] ...	...	10	...	...	1·7
Wheat, whole[127] ...	...	4 6	100·0 68·0	... ...	... ...
Wheat, whole[42] ...	...	8	...	...	1·2
Wheat, whole[62] ...	...	5	83·0	91·7	...
Wheat, whole[70] ...	...	7	...	...	1·3
Wheat, whole[114] ...	14·7	5 7 8 9	... ...	... ...	0·9 0·8 0·9 1·1
Wheat, whole[129] ...	...	6 9	... ...	... ...	0·5; 0·8 0·8
Wheat, whole[130] ...	...	9	...	...	0·9
Wheat, whole[142] ...	...	5 8 9	... ...	... ...	0·9 0·9; 1·0 1·1
Wheat, whole[80] ...	14·4	10	...	...	1·4

TABLE I. *Nutritive Value of Cereal Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Wheat, whole[110] ...	...	9	...	...	1·7
		11	...	...	1·8
Wheat, whole[111] ...	12·6	5	66·0	93·0	...
Wheat, whole[112] ...	...	5	...	...	1·3
Wheat, whole[113] ...	...	10	...	...	1·2
Wheat, whole[119] ...	...	6	68·0	...	...
Wheat, whole[123] ...	14·0	10	...	...	1·4
Wheat, whole[125] ...	...	12	63·0	88·0	...
Wheat, whole[132] ...	...	5	...	...	—ve
		10	...	...	1·3
Wheat, whole[134] ...	...	10	67·0	91·0	...
Wheat, whole[140] ...	...	11	...	...	1·0
Wheat, whole[146] ...	7·6	8	67·0	...	...
Wheat, whole[147] ...	...	9	...	...	1·2
Wheat, whole, hard, spring[59]	14·2	5	...	...	1·7
		8	...	...	1·6
		10	...	...	1·6
		12	...	...	1·5
Wheat, whole, hard, var. Manitoba II[117] ...	15·5	10	...	...	1·7
Wheat, whole, hard, var. Garnet[117] ...	14·5	10	...	...	1·8
Wheat, whole, semihard, var. Ostka Chlopicka[117]...	13·2	10	...	...	1·7
Wheat, whole, soft, winter[59]	11·0	5	...	...	1·7
		8	...	...	1·2
		10	...	...	1·7
Wheat, whole, soft, var. Dankowska Graniatka[117]	10·8	10	...	...	1·7
Wheat, whole, water-cooked[123] ...	...	10	...	...	1·5
Wheat, whole, water-cooked[125] ...	...	12	66·0	87.0	...
Wheat, whole, toasted[125] ...	...	11	52·0	73·0	...
Wheat, whole, toasted[137] ...	11·3	5	90·0*	80·5*	...
Wheat, shredded[70] ...	...	7	...	...	1·1
Wheat, raw, cracked[125] ...	10·0	10	64·0	...	...
		11	...	...	1·7
Wheat, water-cooked cracked[125] ...	...	11	67·0	...	...
Wheat, toasted, cracked[125]	...	11	52·0	...	...
		13	...	...	1·1
Wheat, torn[137] ...	10·9	5	92·8*	81·0*	...

—ve denotes negative growth.

* determined by human metabolism experiments.

TABLE I. *Nutritive Value of Cereal Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Wheat, flaked[137] ...	11.7	5	82.1*	88.0*	...
Wheat, inflated[137] ...	15.1	5	79.8*	82.5*	...
Wheat, puffed[125] ...	...	13	...	...	0.7
Wheat, puffed[126] ...	13.2	10	...	...	—ve
Wheat flour, whole ('atta')[63] ...	...	5 10	... ...	... ...	1.4 1.4
Wheat bread, whole[143] ...	...	5	73.0	...	...
Wheat bread, whole[148] ...	...	8	56.1	84.7	...
Wheat bread, whole peeled[149] ...	...	5	79.6*	93.0*	...
Wheat biscuit, whole[149] ...	...	5	81.6*	85.2*	...
Wheat endosperm[119] ...	...	7	61.0	...	...
Wheat endosperm[137] ...	11.6	5	79.7*	97.2*	...
Wheat flour, milled[62] ...	...	5	63.5	94.5	...
Wheat flour, milled[81] ...	9.8	7	...	...	0.7
Wheat flour, milled[82] ...	...	9	...	...	0.8
Wheat flour, milled[86] ...	10.2	8	...	...	0.7
Wheat flour, milled[150] ...	...	9	...	...	0.7
Wheat flour, patent[60] ...	...	6 9	... ...	... ...	0.7 0.9
Wheat flour, patent[80] ...	13.5	10	...	...	0.8
Wheat flour, patent[147] ...	...	9	...	...	0.8
Wheat flour, white[52] ...	...	10	...	...	1.2; 1.5
Wheat flour, white[127] ...	...	3 7	84.0 61.0	... ...	... ...
Wheat flour, white[61] ...	...	6	...	...	0.7
Wheat flour, white[118] ...	...	9	...	...	0.8; 0.9
Wheat flour, white[76] ...	...	12	...	...	0.7
Wheat flour, white[117] ...	10.5	10	...	...	1.0
Wheat flour, white[134] ...	...	10	52.0	100.0	1.0
Wheat flour, white[151] ...	...	...	41.0*	96.9*	...
Wheat flour, white (85 per cent extraction, National wheat meal)[52] ...	...	10	...	...	1.5; 1.7
Wheat flour, white (80 per cent extraction)[61] ...	...	6 9	... ...	... ...	0.7; 0.8 1.3
Wheat flour 'First Clear'[80]	16.2	10	...	...	0.8
Wheat flour, 'Second Clear'[80] ...	17.4	10	...	...	1.2
Wheat ('Red dog') flour[80]	17.7	10	...	...	2.1
Wheat bread, white[117] ...	10.6	10	...	...	1.0
Wheat bread, white[125] ...	7.5	9	...	...	1.5
Wheat bread, white[131] ...	...	10	45.0	93.0	1.1
Wheat bread, white[143] ...	...	5	74.0	...	...
Wheat bread, white[144] ...	11.0	9 10	... ...	... ...	0.8 1.1
Wheat bread, white[149] ...	...	5	74.6* 75.3*	98.3*; 99.4*	...

—ve denotes negative growth.

* determined by human metabolism experiments.

TABLE I. *Nutritive Value of Cereal Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Wheat bread from white flour of 70 per cent extraction[148] ...	...	8	51·2	91·4	...
Wheat bread from white flour of 80 per cent extraction[148] ...	...	8	53·6	92·0	...
Wheat bread from white flour of 85 per cent extraction[148] ...	...	8	53·2	89·1	...
Wheat bread, white, crumb[125] ...	...	14	...	...	1·0
Wheat bread, white, crust[125] ...	...	16	...	...	1·0
Wheat bread, white, toasted[125] ...	...	12	...	...	1·0
Wheat rolls[144] ...	11·5	6	...	...	1·1
		10	...	...	1·0
Wheat flour, granular[152] ...	...	10	52·0	100·0	...
Wheat semolina[117] ...	9·7	9	...	...	1·7
Wheat pollard[116] ...	...	...	84·0	99·0	...
Wheat shorts[80] ...	17·4	10	...	...	2·5
Wheat bran[80] ...	16·0	10	...	...	2·1
Wheat bran[116] ...	...	...	74·0	98·0	...
Wheat bran protein-extracted[153] ...	...	...	57·0‡	...	...
Wheat germ[80] ...	29·9	10	...	...	2·9
Wheat germ[92] ...	28·5	5	...	...	2·1
		9	...	...	2·9
		10	...	...	2·8
		11	...	...	2·5
		12	...	...	2·4
Wheat germ[94] ...	34·3	10	...	...	2·5
		15	...	...	1·8
		18	...	...	1·6
Wheat germ[119] ...	...	7	69·0	...	...
Wheat germ[127] ...	...	4	90·0	...	...
Wheat germ[131] ...	28·8	10	...	...	2·2
Wheat germ[135] ...	...	...	75·0	95·0	...
Wheat germ, defatted[80] ...	34·8	10	...	...	2·9
Wheat gluten, raw[76] ...	...	12	...	...	0·4
Wheat gluten, raw[125] ...	...	6	83·0	98·0	...
		8	66·0	...	...
		10	...	...	1·3
		12	66·0	95·0	...
		15	...	...	1·3
		18	...	...	1·4
		21	...	...	1·2
		24	...	...	1·0

‡ denotes Net Protein Utilisation (Biological value × Coefficient of true digestibility.)

TABLE I. *Nutritive Value of Cereal Proteins*

SOURCE	Protein content: N×6·25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Wheat gluten, toasted[125] ...	...	6	64·0	96·0	...
		8	...	...	0·9
		10	54·0	...	...
		12	55·0	90·0	1·0
		15	...	...	0·9
		18	...	...	1·1
		21	...	...	1·1
		24	...	...	0·9

TABLE II. AMINO ACID COMPOSITION

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Bajra or Cambu (*Pennisetum typhoideum*)[29, 30, 31] ...	11·3	8·1	1·7	3·8	...	1·9
Bajra, strain CO-1[154] ...	13·3	6·8	3·4	3·7	...	1·1
Bamboo seeds (*Bambusa arundinacea*)[155] ...	12·0	...	...	...	4·6	...
Barley (*Hordeum vulgare*)[36]	18·1	2·8	1·7	2·2	1·1	1·1
Barley, var. Newal[33] ...	15·4	4·7	1·4	3·2	...	...
Barley, pearled[156] ...	11·6	4·5	1·8	2·4	...	...
Barley, malt[36] ...	15·0	3·3	2·0	4·0	1·3	1·3
Canihua (*Chenopodeum pallidiculae*)[17] ...	14·1	7·9	2·5	6·0	...	0·8
Corn, whole (*Zea mays*)[36] ...	9·4	4·3	3·2	3·2	2·1	0·5
Corn, whole[47] ...	...	4·4	2·3	2·5	...	0·6
Corn, whole[157] ...	...	4·8	2·5	2·3	6·0	0·6
Corn, whole[158] ...	...	4·0	2·4	2·5	6·1	0·6
Corn, whole[159] ...	9·1	...	...	...	...	...
Corn, whole, yellow[156] ...	13·9	4·7	2·2	2·3	...	...
Corn, whole, low protein[3] ...	7·6	6·1	2·2	3·0	3·7	1·2
Corn, whole, low protein[67] ...	9·8	...	...	3·1	...	0·9
Corn, whole, low protein ($D_{50} \times B_8$)[160] ...	9·0	...	...	3·1	...	0·9
Corn, whole, high protein[3]	11·4	5·3	2·2	2·4	4·1	1·0
Corn, whole, high protein[67]	14·3	...	...	2·7	...	0·7
Corn, whole, high protein ($NY_3 \times D_{59}$)[160] ...	13·0	...	...	2·8	...	1·0
Corn bread, whole ('Tortilla')[47] ...	...	3·7	1·7	2·2	...	0·4
Corn endosperm[158] ...	...	3·1	1·7	1·1	6·2	0·6
Corn germ[98, 99] ...	...	6·8	2·7	5·8	4·9	1·3
Corn germ[157] ...	...	8·1	3·0	5·8	5·6	1·3
Corn germ[161] ...	...	5·6	3·0	5·3	...	...
Corn germ[162] ...	...	10·1	3·6	5·2	...	3·6
Corn gluten[98] ...	...	3·1	1·7	1·1	6·2	0·6
Corn gluten[157] ...	...	3·1	2·1	1·5	6·3	0·6
Corn gluten[163] ...	...	3·1	1·6	0·8	6·7	0·7
Corn gluten meal[159] ...	48·0	...	...	...	...	...
Corn albumins[98] ...	...	5·4	6·7	low	3·8	0·7
Corn protein (Zein)[157] ...	...	1·8	7·8	0·0	5·2	0·1
Jowar or Cholam (*Sorghum vulgare*)[29, 30, 31] ...	7·6	6·8	1·6	3·4	...	1·2
Jowar[164] ...	10·2	...	...	...	...	...
Jowar, strain N-1[154] ...	14·0	5·6	2·5	2·9	...	0·4
Jowar, strain CO-7[154] ...	14·1	6·5	3·1	3·1	...	0·2
Jowar, strain H-1[154] ...	12·7	6·3	2·1	3·6	...	0·4
Kodra, Coimbatore strain (*Paspalum scorbiculatum*)[15]	7·2	4·0	1·8	2·1	...	0·7
Kodra, Bombay strain[15] ...	4·8	4·8	2·0	3·3	...	0·7
Milo (*Sorghum vulgare*)[26] ...	11·9	3·4	2·5	2·5	1·7	0·8
Milo[159] ...	12·0	...	...	...	...	...

* (C: Chemical; CC: Chromatographic;

ACIDS							Method of Estimation*
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
4·3	...	1·8	3·8	9·5	5·9	6·3	M
3·1	...	2·4	2·8	9·2	4·0	4·7	M
6·0	...	1·4	6·5	7·4	3·7	5·1	CC
3·9	...	1·1	2·2	5·5	3·9	3·9	M
4·8	...	1·2	3·0	6·6	4·1	4·9	M
5·7	...	1·0	3·6	...	...	5·1	M
4·0	...	1·3	2·7	6·0	4·7	4·7	M
3·6	1·1	1·8	4·8	5·8	6·8	4·6	...
5·3	...	2·1	3·2	14·9	6·4	5·3	M
4·4	...	1·9	4·7	19·6	...	5·4	M
5·0	1·5	3·1	3·7	15·0	6·4	5·3	MM
4·5	1·1	4·0	3·6	22·0	3·4	5·0	MM
4·3	...	...	...	10·2	4·1	5·1	M
4·8	...	1·4	3·9	...	...	5·3	M
4·1	1·9	2·1	4·9	9·3	3·6	7·5	M
...	1·5	2·0	...	...	...	...	M
...	...	1·2	...	...	...	...	M
4·8	1·9	1·9	4·7	12·6	3·9	7·1	M
...	1·3	1·7	...	...	...	...	M
...	...	1·4	...	...	...	...	M
4·3	...	1·7	3·5	18·9	...	5·4	M
6·6	1·2	5·5	4·0	25·0	5·0	5·0	MM
5·6	1·2	2·6	4·4	16·3	3·7	5·8	MM
5·0	1·2	1·6	4·4	7·1	4·2	5·3	MM
3·3	...	1·5	4·5	7·1	3·8	5·3	M
2·8	...	4·6	4·2	7·7	4·1	5·9	MM
6·6	1·2	5·5	4·0	24·7	4·9	4·6	MM
6·6	1·5	2·5	4·0	16·0	5·1	5·7	MM
6·4	1·1	2·5	4·1	24·0	5·0	5·0	MM
5·3	...	...	...	15·8	5·1	5·7	M
1·7	0·5	...	3·9	11·3	1·3	2·5	MM
6·4	1·0	2·3	3·0	23·7	7·3	3·0	MM
5·1	...	1·7	3·9	12·9	6·1	5·9	M
...	2·4	2·1	...	...	...	...	C
4·8	...	2·8	2·6	8·9	4·0	4·3	M
2·5	...	2·0	3·2	10·3	4·6	4·9	M
4·2	...	2·5	2·7	9·5	4·8	4·3	M
6·9	...	2·8	3·8	8·5	5·3	5·6	M
9·1	...	3·2	3·8	10·7	7·7	7·3	M
5·0	...	0·8	2·5	15·1	5·9	5·9	M
4·0	...	...	...	10·6	4·3	4·7	M

M: Microbiological; MM: Miscellaneous).

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Oats, whole (*Avena sterilis*)[157]	...	6·8	2·3	3·6	4·5	1·3
Oats, whole[159] ...	11·6	...	...	...	...	...
Oats, whole[165] ...	...	6·7	1·5	3·4	3·2	1·3
Oats, whole, var. Victory[33] ...	14·3	6·1	1·3	3·3	...	...
Oats, whole, var. Richland[34]	11·5	2·1	0·6	1·8	12·0	0·3
Oats, whole, commercial[34] ...	13·9	3·7	0·9	1·3	7·4	0·4
Oats, whole, (average of 14 varieties from 1947 harvest)[35] ...	12·4	...	...	3·1	...	1·2
Oats, whole, (average of 14 varieties from 1949 harvest)[35] ...	13·5	...	...	3·6	...	1·1
Oats, whole, finely ground[36]	16·9	4·1	2·4	3·6	1·2	0·6
Oats, rolled[34] ...	18·4	3·9	1·3	1·1	2·9	1·5
Oats, rolled[156] ...	17·1	7·4	2·2	3·0	...	...
Oats, rolled[163] ...	...	6·0	2·2	3·3	4·6	1·2
Oats middlings[34] ...	21·5	3·8	1·2	0·6	4·7	...
Oats 'shorts'[34] ...	14·1	3·5	0·7	1·3	6·7	...
Quinoa (*Chenopodium quinoa*)[17] ...	11·0	7·4	2·7	6·6	...	1·1
Ragi (*Eleucine coracana*)[29, 30, 31] ...	3·7	5·2	1·5	3·4	...	1·6
Ragi[164] ...	7·1	...	...	...	...	...
Ragi[166] ...	4·8	...	...	...	...	...
Ragi[167] ...	7·9	...	...	3·1	...	1·1
Ragi[168] ...	8·0	1·5	0·3	1·7	...	1·0
Ragi protein[138] ...	...	1·5	1·4	0·5	5·3	1·6
Rajkeera (*Amaranthus paniculatus*)[15] ...	9·8	14·8	2·9	8·2	...	0·9
Rajkeera, raw[155] ...	14·5–16·0	...	...	...	3·3	...
Rala or Italian millet (*Setaria italica*)[15] ...	10·6	3·6	2·1	2·2	...	1·0
Rice, whole (*Oryza sativa*)[29, 30, 31] ...	8·4	10·3	1·6	3·9	...	1·2
Rice, whole[32] ...	7·7	3·3	0·8	3·4	...	1·0
Rice, whole[47] ...	8·3	6·3	2·1	3·3	...	1·5
Rice, whole[169] ...	...	...	...	4·1	...	1·0
Rice, whole (average for 14 strains)[154] ...	8·3	12·7	4·4	3·4	...	0·7
Rice, whole, cooked[47] ...	7·3	5·8	1·8	3·3	...	1·7
Rice, white[156] ...	7·9	8·7	2·3	2·8	...	...
Rice, white[157] ...	...	7·2	1·7	3·2	5·7	1·3
Rice, white[163] ...	...	7·2	1·5	3·2	5·6	1·3
Rice, polished[32] ...	6·4	4·0	0·9	4·4	...	1·0
Rice, polished[164] ...	6·9	...	...	...	...	...
Rice, parboiled and polished[170] ...	6·1	8·1	1·2	3·3	5·4	...
Rice bran[32] ...	13·4	2·6	0·7	3·3	...	0·7
Rice bran[159] ...	16·0	...	...	...	...	...
Rice polishings[32] ...	12·4	2·2	0·6	3·6	...	0·9
Rice polishings[159] ...	15·6	...	...	...	...	...
Rice germ[101] ...	14·9	10·5	2·9	11·5	6·2	1·8
Rye, whole (*Secale cereale*)[36]	18·1	3·3	2·2	3·3	1·1	0·6
Rye, whole[156] ...	12·4	5·4	2·2	3·3	...	...
Rye, whole[133] ...	...	4·3	1·7	4·2	...	1·3
Rye, whole[171] ...	12·2	4·3	1·7	4·2	...	1·3

ACIDS							Method of Estimation
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
5·6	1·8	2·0	3·6	8·0	4·9	5·4	MM
4·5	...	...	...	6·4	4·5	5·7	M
4·8	1·8	1·5	3·4	5·7	5·1	6·6	M
4·7	...	1·2	3·0	7·0	5·0	5·7	M
...	0·6	...	...	...	...	...	C
...	0·6	...	...	...	...	...	C
...	...	1·2	...	6·4	...	...	M
...	...	1·3	...	7·5	...	...	M
4·7	...	1·2	2·4	6·5	4·1	4·1	M
...	...	...	...	...	...	...	C
4·6	...	1·0	3·6	...	...	5·3	M
6·6	1·8	2·4	3·5	8·3	5·6	6·3	MM
...	...	...	...	...	...	...	C
...	...	...	...	...	...	...	C
3·5	1·0	2·4	4·8	7·1	6·4	4·0	...
4·4	...	3·0	3·5	9·5	6·4	6·7	M
...	3·2	3·9	...	...	...	...	C
...	...	5·6	...	...	...	...	C
2·7	...	1·9	2·9	5·9	2·1	6·3	M
1·6	...	...	0·0	...	...	...	M
...	2·5	...	...	...	...	...	C
4·8	...	2·5	4·4	8·0	6·9	6·1	M
5·1	...	1·8	7·7	6·1	3·2	3·5	CC
6·7	...	2·8	3·1	16·7	7·6	6·9	M
4·6	...	2·2	3·4	8·0	6·0	6·1	M
...	1·2	...	...	...	...	...	C
4·6	...	1·9	4·5	9·7	...	6·7	M
2·8	...	1·0	2·6	5·4	3·0	5·0	M
5·5	...	3·6	4·7	9·6	6·2	7·3	M
4·8	...	2·0	4·1	9·5	...	6·8	M
4·6	...	1·4	3·6	...	...	6·3	M
5·0	1·3	3·0	3·8	8·2	5·2	6·2	MM
6·7	1·4	3·4	4·1	9·0	5·3	6·3	MM
...	1·2	...	...	...	...	...	C
...	3·9	4·5	...	...	...	...	C
5·6	1·2	2·8	3·4	...	...	5·5	CC
...	1·0	...	...	...	...	...	C
2·9	...	...	...	4·3	3·1	4·4	M
...	1·1	...	...	...	...	...	C
2·6	...	...	...	3·7	2·6	3·8	M
5·0	1·1	2·8	14·6	5·6	4·2	6·3	M
3·9	...	0·6	2·2	5·5	3·9	3·9	M
3·0	...	1·1	3·9	...	...	5·0	M
5·6	...	1·3	3·0	6·2	4·0	5·0	MM
5·6	...	1·3	3·0	6·2	4·0	5·0	M

SOURCE	Protein content %	AMINO: Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Samai (*Panicum miliare*)[15] ...	11.0	4.7	1.9	1.8	...	0.6
Sorghum, var. Kelo (*Andropogon sorghum*)[167] ...	12.1	...	...	1.8	...	0.8
Tenai, strain N-1 (*Setaria italica*)[151] ...	10.5	7.0	3.5	2.8	...	0.7
Tenai, strain H-2[154] ...	11.0	7.2	4.3	2.4	...	0.8
Wheat, whole (*Triticum aestivum*)[29, 30, 31] ...	10.3	5.2	1.5	2.2	...	1.1
Wheat, whole[36] ...	16.3	3.1	2.5	2.5	0.6	1.2
Wheat, whole[156] ...	19.2	4.5	2.0	2.5	...	...
Wheat, whole[157] ...	...	4.3	2.1	2.7	4.0	1.2
Wheat, whole[158] ...	...	3.0	1.2	2.7	3.8	1.0
Wheat, whole[159] ...	15.2	...	...	...	...	...
Wheat, whole[161] ...	...	3.3	2.6	2.7	...	1.0
Wheat, whole[163] ...	...	4.2	2.1	2.7	4.4	1.2
Wheat, whole[154] ...	11.7	...	...	...	...	...
Wheat, whole[166] ...	10.3	...	...	...	...	...
Wheat, whole[171] ...	13.9	4.2	2.0	2.9	...	1.4
Wheat, whole[172] ...	13.4	3.8	1.7	2.8	...	1.0
Wheat, whole (average for 5 strains)[154] ...	10.2	10.4	1.6	3.3	...	1.1
Wheat, whole, var. Fulhio (soft winter)[24] ...	14.6	2.4	0.5	6.0	3.5	0.5
Wheat, whole, var. Marquis (hard spring)[24, 173] ...	20.7	2.5	1.4	7.3	4.2	0.4
Wheat, whole, var. Tenmarq (hard winter)[24, 173] ...	16.1	2.4	0.7	7.6	3.5	0.4
Wheat, whole, var. Marquis[33]	18.9	4.5	1.6	2.2	...	...
Wheat endosperm[158] ...	...	3.9	2.2	1.9	3.8	1.0
Wheat, inner endosperm[172]	11.9	2.9	1.7	1.9	...	0.9
Wheat, outer endosperm[172] ...	14.4	4.5	1.7	2.6	...	1.1
Wheat flour, milled[157] ...	...	3.9	2.2	1.9	3.8	0.8
Wheat flour, patent[171] ...	14.3	3.1	1.5	2.2	...	1.0
Wheat flour, patent, from hard spring wheat (var. Marquis, 74% extraction)[173]	18.9	2.2	1.0	5.2	2.5	0.6
Wheat flour, patent, from hard winter wheat (var. Tenmarq, 74% extraction)[173] ...	13.3	2.5	0.8	6.5	3.7	0.7
Wheat ('Red dog') flour[36] ...	23.8	3.8	2.5	2.9	0.8	0.8
Wheat bread, white[157] ...	...	3.5	2.3	2.8	4.4	1.3
Wheat flour, granular[36] ...	15.0	2.7	2.0	2.0	1.3	0.7
Wheat middlings, standard[36]	23.1	5.6	2.6	2.6	1.3	0.9
Wheat 'shorts' from hard winter wheat, var. Tenmarq[173] ...	20.1	3.4	0.2	10.0	4.4	0.3
Wheat bran[36] ...	18.8	4.8	2.7	3.2	1.1	1.6
Wheat bran[157] ...	...	7.5	1.7	3.9	...	1.3
Wheat bran[159] ...	16.0	...	...	...	...	...
Wheat bran[172] ...	12.3	7.5	1.7	3.9	...	1.8
Wheat bran from hard winter wheat, var. Tenmarq[173] ...	17.2	1.9	0.3	10.8	4.8	0.3
Wheat germ[99] ...	...	6.0	2.5	5.5	3.8	1.0
Wheat germ[157] ...	...	6.0	2.5	5.5	3.8	1.0
Wheat germ[172] ...	32.6	6.2	3.0	5.4	...	0.9

ACIDS							Method of Estimation
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
4.8	...	2.3	3.4	10.9	6.7	6.1	M
2.6	...	0.8	2.4	8.7	2.9	5.2	M
5.2	...	3.3	3.7	12.7	5.7	5.9	M
5.3	...	3.6	3.3	15.0	5.6	6.0	M
5.3	...	1.2	2.6	6.5	3.5	4.0	M
4.3	...	1.2	2.5	6.1	4.3	4.3	M
3.8	...	1.0	3.0	...	...	4.1	M
5.1	1.8	2.5	3.3	7.0	4.0	4.3	MM
5.7	1.3	3.0	3.3	13.0	4.0	3.4	MM
4.4	...	...	...	5.6	3.8	4.8	M
4.2	...	1.3	3.3	6.4	4.1	3.6	M
5.7	1.8	2.5	3.3	6.8	3.6	4.5	MM
...	2.4	2.3	...	...	...	...	C
...	...	2.1	...	...	...	...	C
5.1	...	1.2	2.5	6.8	3.6	4.5	M
3.7	1.7	1.3	2.8	8.3	7.0	4.0	M
4.5	...	2.6	3.7	7.8	4.8	4.1	M
...	1.1	...	...	...	...	...	C
...	1.3	...	...	...	...	...	C
...	1.0	...	...	...	...	...	C
5.0	...	1.2	2.7	6.4	4.5	4.4	M
5.5	1.8	3.0	2.6	12.0	4.0	3.0	MM
4.0	1.6	1.1	2.6	9.1	7.0	3.7	M
3.4	1.9	1.4	2.7	8.0	6.6	4.0	M
5.5	1.9	2.0	2.7	7.0	4.2	4.1	MM
5.6	...	1.0	2.5	7.5	3.7	4.2	M
...	1.6	...	...	...	...	...	C
...	1.7	...	...	...	...	...	C
2.1	...	0.8	2.5	5.5	4.2	5.0	M
5.0	2.1	2.0	2.8	...	...	...	MM
4.7	...	0.7	2.0	6.7	4.7	4.0	M
4.3	...	0.9	2.6	5.6	4.8	5.6	M
...	0.6	...	...	...	...	...	C
3.2	...	1.1	2.1	5.9	4.3	4.8	M
3.0	1.5	1.3	2.5	6.5	4.5	4.1	MM
3.3	...	...	...	5.2	3.4	5.1	M
2.5	1.5	1.1	2.9	6.5	4.5	4.1	M
...	0.5	...	...	...	...	...	C
4.2	0.6	2.0	3.8	7.4	3.0	4.1	MM
3.0	1.4	1.3	6.3	6.7	4.5	4.3	MM
2.5	1.4	1.3	6.3	7.3	5.2	4.2	M

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Wheat germ, defatted[162] ...	...	9·6	4·3	5·1	...	2·9
Wheat gluten[98] ...	...	3·9	2·2	1·9	3·8	0·8
Wheat gluten[163] ...	...	3·9	2·2	2·0	3·8	1·0
Wheat gluten meal[36] ...	44·4	2·7	2·3	1·8	2.5	0·5
Wheat gluten feed[36] ...	28·8	2·5	2·8	2·8	1·4	0·3

ACIDS							Method of Estimation
Phenyl-alanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
4·1	...	2·8	3·0	6·6	3·8	6·3	MM
5·5	1·9	3·0	2·7	12·0	3·7	3·4	MM
5·5	1·9	1·0	2·7	7·5	3·7	4·2	MM
5·6	...	2·0	3·1	16·4	5·4	4·7	M
3·5	...	1·4	3·5	10·4	4·5	5·2	M

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CHAPTER II

LEGUMES*

FOR vegetarians, as also those who cannot afford the costly protein-rich animal foods, legumes are the most important source of proteins in the dietary[1, 2]. Legume proteins provide certain essential amino acids in which cereal proteins are deficient and thereby enhance the overall nutritive value of the proteins in the mixed diet[3]. Inclusion of legumes in processed foods like dried soup powders[4, 5] and multipurpose food[6] helps to improve the palatability by masking the flavour of the other constituents. The preparation of milk substitutes from legumes has been reviewed[7, 8]. The nutritive value of legume proteins has been extensively investigated and we are today in a position to lay down diet schedules based on blends of legumes and cereals as would meet fairly adequately the protein requirements of the body[3]. In addition to this, there have been a constant search for new legumes of high protein content[9, 10] and suggestions for the utilisation of unfamiliar legumes[11]. Harris and his team from the Massachusetts Institute of Technology have collected a large volume of data on Central American legumes[12-20] and more of these are still being investigated.

Apart from focusing attention on new and hitherto unfamiliar sources of legume proteins, recent work has also shown the possibility of wide variations not only in regard to protein content of legumes but also in respect of the amino acid make-up of the protein as influenced by various factors, such as variety[2, 21] or fertilizer treatment[22].

Protein content: The protein content of most legumes falls within the range 20-30 per cent (Tables III and IV), prominent exceptions being Agathi seeds[9] (*Sesbania grandiflora*) which contain 68 per cent protein and lupin seeds[10] (*Lupinus luteus*) which contain 79 per cent protein. It has been reported that sulphur-containing fertilizers reduce the protein content of peas[22] (*Pisum sativum*). The non-protein nitrogenous constituents of legumes have been investigated[23, 24].

The proteins of legumes are chiefly globulins with certain amount of albumins in a few cases. The albumin of peas differs from the globulin in having a higher content of tryptophan and lysine[25].

Amino acid composition: The amino acid composition of the proteins of different legumes are presented in Table IV. In general, methionine is the major limiting amino acid in legume proteins[10, 21, 26-52]. Crystallization of phaseolin, the protein isolated from Ukrainian beans (*Phaseolus vulgaris*), is reported to bring down its methionine content

* Excluding soya bean.

further[44]. White sweet lupin (*Lupinus albus*) proteins, however, have been shown to contain 2.6 per cent methionine, rather exceptional for a legume protein[53]. When methionine is added to the diet, the biological value of legume proteins, in general, is known to improve[29, 30, 46, 48, 49, 51]. When supplemented in this manner, Alaska field pea proteins become superior to casein in nutritive value[41]. The proteins of split peas, lentils (*Lens culinaris*) and red gram or pigeon peas (*Cajanus cajan*) do not produce good growth even when supplemented with methionine[29]. Supplementation with other deficient amino acids like tryptophan or threonine is also ineffective, but, in presence of methionine, tryptophan and/or threonine significantly enhance the nutritive value further; thus, maximum improvement has been obtained with a combination of methionine, tryptophan and threonine, raising the protein efficiency ratio of Bengal gram or chick peas (*Cicer arietinum*) from 1.3 to 2.3 and that of lentils from 0.7 to 2.6[45]. Variations in the availability of methionine from the proteins of different legumes have been reported[21, 43, 50]. The methionine[21] present in Bengal gram (chick peas) is reported to be more readily available to the rat than that present in certain varieties of peas, lima beans (*Phaseolus lunatus*) and snap beans (*Phaseolus vulgaris*).

Next to methionine, cystine is another general deficiency in legume proteins[10, 36-40, 44, 54]. However, the proteins of Bengal gram (chick peas),[33] lupin seeds[10], lentils[55] and string beans[55] (*Phaseolus vulgaris*) are reported to contain fair percentages of cystine. Sulphur-containing fertilizers increase the cystine content of pea proteins[22]. The availability of cystine, too, varies among different legumes[43].

Other general deficiencies in legume proteins are tryptophan[26, 35, 40, 55, 56] and isoleucine[39, 42, 47, 53]. The proteins of red gram (pigeon peas), in particular, are very low in tryptophan[29, 30, 37]. There are, however, some unconfirmed reports to the effect that the proteins of certain legumes like Bengal gram (chick peas)[43], black gram[43] (*Phaseolus mungo*) and white sweet lupin seeds[53] are rich in tryptophan. The availability of tryptophan from legume proteins is reported to be high except in the case of red gram (pigeon peas) proteins[43].

In addition, specific deficiencies of other essential amino acids in the proteins of particular legumes have also been reported, like phenylalanine in horse beans[40] (*Vicia faba*); threonine in horse beans[40], subterranean clover seeds[42] (*Trifolium subterraneum*) and Bengal gram (chick peas)[57] and valine in peas[42].

Legume proteins are considered to be good sources of lysine[35]. The protein in a sample of pea analysed at Coonoor (India) has been found to contain 11.4 per cent lysine[58]. The proteins of Agathi seeds are, however, deficient both in lysine and in methionine[9].

Nutritive value: The proteins of legumes, as a class, are not well balanced in respect of all the essential amino acids and, in general,

their biological value is not of a high order[29, 46]. The performance of growing children on predominantly legume diets has been reported to be inferior in a number of respects to their performance on predominantly meat diets[59]. Certain legumes, however, contain proteins of fairly high biological value—for instance, Alaska peas[60] and Bengal gram (chick peas) [21, 28-30, 61]. The latter is also reported to contain a growth-promoting factor for guinea-pigs[62].

Factors influencing nutritive value

Vitamin B_{12}: Vitamin B_{12} has no influence on the growth-promoting value of lentil protein at 12 per cent level in the diet, but its biological value is significantly increased; at 18 per cent level, however, this vitamin also increases its growth-promoting value[63].

Germination: While the growth-promoting value[64] and the digestibility[65] of the proteins of Bengal gram (chick peas) increase on germination, the biological value[65] registers a small decrease. Among other legumes investigated, germination improves the growth-promoting value of the proteins of black gram[64] and lentils[64] but not that of the proteins of peas[64, 66] and green gram[48, 64] (*Phaseolus aureus*). Protein break-down is reported to occur in peas, with increased formation of amides and ammonia, during germination in air and also on prolonged soaking in water[67].

Maturity: The proteins of lima beans in the fresh, immature state are superior in nutritive value to the proteins in the mature, vine-ripened legume[68], but the effect of maturity on the nutritive value of pea proteins is a subject of controversy[34, 66, 68].

Processing: Heat-processing increases the digestibility of legume proteins[69-71], removes saponins responsible for the typical bitter taste in raw legumes and generally improves their flavour[72]. The biological values of the proteins in several legumes have been compared when fed raw and after autoclaving. Those reported to improve on heat-processing include the field bean[51] (*Dolichos lablab*), navy bean[68] (*Phaseolus vulgaris*), kidney bean[68] (*Phaseolus vulgaris*), pinto bean[49, 68, 73] (*Phaseolus vulgaris*), jack bean[74, 75] (*Canavalia ensiformis*), velvet bean [75, 76, 77] (*Mucuna deeringianum*), adsuki bean[78] (*Phaseolus angularis*), horse bean[75], horse gram[51,79] (*Dolichos biflorus*) and Khesari dhal[48] (*Lathyrus sativus*). Those reported not to so improve include the partridge pea[75] (*Chamaecrista fasiculata*), guar bean[75] (*Cyamopsis psoraloides*), lespedeza[75] (*Lespedeza stipulacea*) and the common vetch[75] (*Vicia sativa*). There are a number of reports in the literature to the effect that the nutritive value of pea proteins is impaired as a result of heat-processing[41, 49, 52, 66, 68, 80-82], but there are also a couple of reports to the contrary[48, 79]. Controversy exists also regarding the effect of heat-processing on the biological value of the proteins present in a number of other legumes, such as Bengal gram (chick peas) [48, 51, 79, 82, 83-86], lentils [48, 51, 75, 81, 82, 87,

green gram[48, 51, 75, 79, 83, 84], black gram[48, 51, 79], red gram (pigeon peas)[48, 51, 69] and cow peas [49, 50, 75, 80, 88] (*Vigna sinensis*). In fact, cooking cow peas makes no difference to the growth-promoting value of cow pea proteins in some samples, while it has a beneficial effect in some others[50]. The effect of canning on the biological value of pea proteins is another subject of controversy[34, 66, 89] and is reported to be influenced by the maturity[34] of the peas and pH[89]. Parching improves the nutritive value of the proteins in Bengal gram (chick peas)[79, 83, 84], green gram[79, 83], black gram [79], horse gram[79] and dried peas[79]. Many legumes contain trypsin inhibitors[90, 91], which, in most cases, are heat-labile[91], but no correlation has been observed between the effect of autoclaving on the nutritive value of protein and the presence or absence of trypsin inhibitor in the raw legume[75].

Supplementary value: The general pattern of distribution of essential amino acids in cereal and legume proteins being dissimilar, they are capable of supplementing each other, with the result that cereal-legume mixtures contain proteins of superior nutritive value[3, 66, 86, 92, 93]. Bread prepared with the addition of pea or bean meal has been reported to possess a higher nutritive value than that prepared from cereal only[94]. Supplementary relationships have been observed between the proteins of Bengal gram (chick peas) and parboiled wheat[86], between the proteins of horse beans and corn[95], between the proteins of peas and cereal germ[96] and between the proteins of peas and meat[97]. Recent studies at Coonoor (India) have shown that the proteins in legumes such as Bengal gram (chick peas), black gram, green gram and red gram (pigeon peas) supplement wheat proteins, jowar proteins and bajra proteins, but not rice proteins[98]. As judged by human metabolism studies, legume proteins are inferior to milk proteins in supplementing rice proteins[99].

Toxicity and ill-effects: Sword beans (*Canavalia gladiata*) and jack beans are reported to contain a sapotoxin which causes nausea and vomitting; cooking in plain water or in water made alkaline with sodium carbonate is said to render them fit for human consumption[100]. Different varieties of Burma beans (*Phaseolus lunatus*) have been shown to contain cyanogenetic glucosides in varying concentrations, which can be detoxicated by moistening the legume flour with water followed by drying[101]. Mucuna seeds (*Mucuna pruriens; Mucuna utilis*) are, in general, rich in proteins[102] and are free from alkaloids and cyanogenetic glucosides[46]. But since the Indian variety of mucuna seeds, *Mucuna pruriens*, contains large quantities of dihydroxyphenylalanine[103], long term effects of feeding this legume require to be investigated[104]. *Mucuna utilis* is reported to be even more toxic than *Mucuna pruriens*[105].

Reports from Spain and Central America indicate that chick peas, when fed to experimental animals as the sole source of protein, produce toxic symptoms[82, 106]. These symptoms, broadly described

as cicerism, are attributed to cicerine, the chick pea protein[107] and also to the fat present in the legume[106]. The toxicity can be ameliorated by the addition of methionine or choline; the latter, though present in sufficient quantities in raw chick peas, is destroyed on cooking[107]. A new vitamin of the B group present in liver extract, other than Vitamin B_{12}, has been reported to be potent in protecting animals against cicerism[106, 108]. Experience with Bengal gram (chick peas) in experimental feeding in India, however, has not confirmed these reports[48, 62, 109].

The incidence of lathyrism in areas where Khesari dhal is consumed is well known[110-117]. Other legumes of the *Lathyrus* species like sweet peas[118-121] (*Lathyrus odoratus*), singletary peas[122] (*Lathyrus pusillus*), perennial peas[123] (*Lathyrus latifolius*), flat peas[121, 123-125] (*Lathyrus sylvestris Wagneri*), *Lathyrus hirsutus*[121], *Lathyrus tingitanus*[121] and *Lathyrus sphaericus*[121] have also been found to possess toxicity in varying degrees. Toxic principles have been isolated from sweet peas[126], singletary peas[127] and flat peas[124]. No information is, however, available regarding the chemical nature of the toxic compounds present in Khesari dhal. It has been reported that dietary protein has an ameliorative action on lathyrism in experimental animals[128, 129]. Though a number of theories have been advanced regarding the toxicology of legumes of the *Lathyrus* species[31, 47, 118, 121, 122, 130], the last word has not been said on the subject and the etiology of human lathyrism still remains to be elucidated.

TABLE III

NUTRITIVE VALUE OF LEGUME PROTEINS

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Aconite bean (*Phaseolus aconitifolius*)[131] ...	27·1	11	57·0	58·5	...
Aconite bean[132] ...	...	5 10	55·9 50·2	82·6 86·5	... ...
Agathi seeds (*Sesbania grandiflora*)[9] ...	69·9	10 10	35·6 35·9*	92·4 89·0*	Nil ...
Bengal gram or Chick pea (*Cicer arietinum*)[21] ...	21·6	10	...	...	1·8*
Bengal gram[45] ...	...	12	...	...	1·3*
Bengal gram[48] ...	23·8	12 12	64·0 ...	86·6 ...	2·0 1·8*
Bengal gram[51] ...	...	12 12	... ...	... ...	1·9 2·0*
Bengal gram[64] ...	...	15	...	...	1·7
Bengal gram[65] ...	28·0	10	78·1	82·1	...
Bengal gram[79] ...	...	5 10	78·2 74·6	85·7 89·1	... ...
Bengal gram[83] ...	...	10 10 10	61·1; 73·0 59·3* 63·7*†	80·5; 92·0 92·0* 93·7*†	1·2 1·7*; 1·8* ...
Bengal gram[86] ...	17·8	10 10	... ...	... ...	1·5 2·1*
Bengal gram[98] ...	...	10	...	...	1·8
Bengal gram[134] ...	28·1	10	78·0	76·0	...
Bengal gram[136] ...	22·1	10	62·0	86·0	...
Bengal gram[137] ...	21·7	10	...	...	0·7
Bengal gram[142] ...	23·9	5 10 15	60·0 52·0 46·0	85·0 85·0 88·0	0·8 1·3 1·1
Bengal gram, germinated[65]	26·8	10	75·6	89·4	...
Bengal gram, parched[79] ...	...	5 10	84·6 78·0	88·6 88·9	... ...
Blackeyed pea (*Vigna sinensis*)[75] ...	22·3	12 12	... ...	... ...	0·5 1·3*
Black gram (*Phaseolus mungo*)[48] ...	24·3	12 12	64·0 ...	90·7 ...	1·2 1·4*

* refers to cooked or autoclaved materials.
† determined by human metabolism experiments.

TABLE III. *Nutritive Value of Legume Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Black gram[51] ...	...	12	...	...	1·5
		12	...	...	1·5*
Black gram[64] ...	...	15	...	...	1·5
Black gram[79] ...	...	5	63·9	85·7	...
Black gram[98] ...	...	10	...	...	1·9
Black gram[135] ...	27·9	11	60·0	83·0	...
Black gram[136] ...	23·5	10	62·0	78·0	...
Black gram[137] ...	24·2	11	...	...	1·0
Black gram, parched[79] ...	...	5	65·9	83·8	...
Cow pea (*Vigna sinensis*)[131]	26·0	10	72·0	58·0	...
Cow pea[136] ...	24·1	10	45·0	78·0	...
Cow pea[71] ...	...	10	...	79·0	...
		10	...	82·6*	...
Field bean (*Dolichos lablab*)[51] ...	...	12	...	...	— ve
		12	...	...	— ve*
Field bean (Hyacinth bean)[71]	...	10	...	56·5	...
		10	...	81·6*	...
Field bean[134] ...	28·7	10	57·0	65·0	...
Field bean[136] ...	24·6	10	41·0	76·0	...
Field pea (*Pisum arvense*)[133]	25·6	6	69·0	...	...
Field pea[135] ...	25·6	10	62·0	70·0	...
Green gram (*Phaseolus aureus*)[48] ...	22·8	12	47·4	90·8	1·2
		12	...	...	1·5*
Green gram[51] ...	...	12	...	...	1·4
		12	...	...	1·3*
Green gram[64] ...	...	15	...	...	1·9
Green gram[79] ...	...	5	50·0	86·9	...
Green gram[83] ...	...	10	47·7; 66·0	74·6; 91·0	0·7
		10	38·6*	83·0*	1·0*
		10	43·0* †	94·0* †	...
Green gram[98] ...	...	11	...	...	1·5
Green gram[135] ...	26·3	11	64·0	82·0	...
Green gram[137] ...	24·8	10	...	...	0·9
Green gram[138] ...	23·8	10	51·0	86·0	...
Green gram[139] ...	23·3	6	63·0	93·0	...
		12	52·0	86·0	...
		15	45·0	93·0	...
Green gram[140] ...	...	10	...	...	1·2
		15	...	...	1·2
Green gram[143] ...	...	10	...	...	1·2
Green gram, parched[79] ...	...	5	70·2	85·2	...

* refers to cooked or autoclaved materials.

— ve denotes negative growth. † determined by human metabolism experiments.

TABLE III. *Nutritive Value of Legume Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Horse bean or broad bean (*Vicia faba*)[86] ...	23·5	10	...	...	1·2*
Horse gram (*Dolichos biflorus*)[51] ...	...	12	...	...	0·7
		12	...	...	1·7*
Horse gram[79] ...	...	6	61·4	77·2	...
Horse gram[134] ...	26·4	10	67·0	59·0	...
Horse gram[136] ...	22·1	10	66·0	73·0	...
Horse gram, parched[79] ...	...	6	69·8	79·4	...
Khesari dhal (*Lathyrus sativus*)[48] ...	28·8	12	41·7	90·6	— ve
		12	...	...	0·4*
Khesari dhal[141] ...	32·2	10	50·0	90·0	0·0
		15	44·0	90·0	0·6
Khesari dhal[143] ...	...	10	...	...	0·3
Kidney bean (*Phaseolus vulgaris*)[86] ...	22·5	10	...	...	1·5*
Kidney bean (Pinto bean)[68]	...	10	...	...	Died
		10	...	...	0·4*
Kidney bean, black[71] ...	...	10	...	64·0	...
		10	...	76·5*	...
Kidney bean, red[71] ...	...	10	...	56·0	...
		10	...	79·5*	...
Kidney bean, vine-ripened[68] ...	...	10	...	...	Died
		10	...	...	0·8*
Kidney bean (Navy bean), vine-ripened[68] ...	...	10	...	...	Died
		10	...	...	0·4–0·9*
Lentil (*Lens culinaris*)[45] ...	...	12	...	...	0·7*
Lentil[48] ...	23·8	12	44·6	92·3	0·5
		12	...	...	0·9*
Lentil[63] ...	...	12	48·0	92·3	0·1
		18	49·5	93·0	0·4
Lentil[51] ...	...	12	...	...	0·9
		12	...	...	0·8*
Lentil[64] ...	...	15	...	...	1·2
Lentil[71] ...	...	10	...	88·3	...
		10	...	92·6*	...
Lentil[86] ...	24·0	10	...	...	1·2*
Lentil[131] ...	28·7	11	58·0	78·0	...

* refers to cooked or autoclaved materials.

— ve denotes negative growth.

TABLE III. *Nutritive Value of Legume Proteins*

SOURCE	Protein content: $N \times 6.25$ %	Level of feeding %	Nutritive Value		
			Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Lentil[137] ...	24·1	10	...	...	0·5
Lentil[138] ...	25·7	10	41·0	88·0	...
Lentil[139] ...	22·6	6	53·0	92·0	...
		11	32·0	90·0	...
		15	25·0	92·0	...
Lentil[140] ...	...	10	...	...	0·6
		15	...	...	0·9
Lentil[143] ...	...	10	...	...	0·6
Lima bean (*Phaseolus lunatus*), average of 4 varieties[21] ...	19·8	10	...	...	— ve–0·7*
Lima bean[71] ...	...	10	...	34·0	...
		10	...	51·3*	...
Lima bean, fresh[68] ...	...	10	...	...	0·2
Lima bean, home-dried[68]	...	10	...	...	1·2
Lima bean, vine-ripened[68]	...	10	...	...	0.0
		10	...	...	1·2*
Lupin seeds, sweet, white (*Lupinus albus*)[53] ...	...	...	58·0	...	...
Pea (*Pisum sativum*)[41] ...	...	10	...	...	0·6*; 0·8*
		10	...	...	1·1
		20	...	...	1·0
Pea[48] ...	21·7	12	49·0	90·7	0·7
		12	...	...	0·9*
Pea[52] ...	...	9	...	60·6	...
		9	...	61·7*	...
Pea[60] ...	...	...	95·1*†‡	...	...
Pea[64] ...	...	15	...	...	1·5
Pea[79] ...	...	5	69·5	81·0	...
Pea[89] ...	...	10	...	...	1·0; 1·2
Pea[96] ...	23·1	10	...	...	1·0*
Pea[97] ...	23·1	10	...	...	1·0*
Pea[141] ...	27·1	10	48·0	91·0	1·0
		15	41·0	89·0	1·0
Pea[143] ...	...	10	...	...	1·0
Pea (average of 9 varieties)[21] ...	27·5	10	...	...	— ve–0·7
Pea, parched[79] ...	...	5	78·2	83·9	...
Pea, green, fresh[68] ...	...	10	...	...	1·9

* refers to cooked or autoclaved materials.

† determined by human metabolism experiments.

‡ denotes egg replacement value. — ve denotes negative growth.

Table III. *Nutritive Value of Legume Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Pea, green, home-dried[68] ...	...	10	...	...	1·2
Pea, green, vine-ripened[68]	...	10 10	... ...	... ...	0·8 0·4*
Pea, yellow, vine-ripened[68]	...	10 10	... ...	... ...	0·6 0·6*
Pea, raw (Alaska)[66] ...	...	10 15	57·3 ...	91·6 ...	1·3–1·4 1·3
Pea (Alaska), immature[66] ...	...	10	...	...	1·2
Pea (Alaska), canned[66] ...	...	10	...	...	0·7
Pea (Alaska), canned[89] ...	...	10	...	...	1·0 ; 1·2
Pea (Alaska), baked[66] ...	...	10	...	...	1·1
Pea (Alaska) germ[66] ...	...	8	...	...	1·6
Pea (Alaska) sprout[66] ...	...	8	...	...	1·2
Red gram or Pigeon pea (*Cajanus cajan*)[48] ...	23·4	12 12	61·0 ...	84·9 ...	−ve 1·3*
Red gram[51] ...	...	12 12	... ...	... ...	1·6 1·6*
Red gram[71] ...	...	10 10	... ...	59·1 59·9*	... ...
Red gram[83] ...	...	10 10	52·0 ; 74·0 61·7*†	67·1 ; 90·0 90·7*†	0·7 ...
Red gram[98] ...	...	11	...	...	1·7
Red gram[133] ...	25·6	5	79·0	...	...
Red gram[135] ...	25·6	9	74·0	71·0	...
Red gram[136] ...	22·7	10	72·0	75·0	...
Red gram[137] ...	23·6	10	...	...	Died
Red gram[142] ...	24·2	5 10 15	55·0 46·0 36·0	76·0 92·0 83·0	0·0 1·0 1·4
Snap bean (*Phaseolus vulgaris*), average of 5 varieties[21]	23·6	10	...	...	−ve–0·2*

* refers to cooked or autoclaved materials.

† determined by human metabolism experiments.

−ve denotes negative growth.

TABLE IV. AMINO ACID COMPOSITION

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Trypto-phan %
Aconite bean (*Phaseolus aconitifolius*)[144] ...	24·5	...	3·3	5·4	5·6	0·7
Agathi seeds (*Sesbania grandiflora*)[145] ...	...	...	...	...	2·7	...
Alfalfa seeds, Ranger (*Medicago sativa*)[146] ...	39·8	8·5	2·2	4·2	2·4	0·7
Bengal gram or Chick pea (*Cicer arietinum*)[21] ...	23·1	...	...	...	...	...
Bengal gram[27] ...	16·1	...	...	...	...	...
Bengal gram[33] ...	17·3	...	...	...	...	...
Bengal gram[37] ...	21·8	6·9	2·3	6·4	...	0·6
Bengal gram[45] ...	...	...	...	6·3	...	0·8
Bengal gram[67] ...	...	...	...	...	...	...
Bengal gram[147] ...	26·2	4·3	3·4	9·2	...	0·8
Bengal gram[148] ...	17·0	6·6	...	11·6	2·0	0·1
Bengal gram, strain No. 482[149] ...	23·1	11·6	5·0	5·9	...	0·7
Bengal gram, strain No. T-87[149] ...	22·0	13·0	3·2	3·0	...	1·0
Blackeyed pea, fresh (*Vigna sinensis*)[150] ...	28·2	6·1	3·3	6·3	...	1·0
Blackeyed pea, dried[150] ...	25·0	6·4	3·2	6·3	...	1·0
Black gram (*Phaseolus mungo*)[33] ...	23·1	...	...	...	...	...
Black gram[35] ...	29·9	...	...	6·7	...	1·1
Black gram[37] ...	25·3	5·7	2·7	6·0	...	0·5
Black gram[43] ...	24·3	...	...	...	...	1·3
Black gram[148] ...	24·0	...	12·8	12·1	2·3	2·1
Black gram, strain No. T-27[149] ...	28·4	9·2	4·0	4·1	...	0·7
Black gram, strain N.P. 6[149]	28·0	10·1	3·6	5·3	...	0·8
Black gram (Ryokoto)[36] ...	23·2	5·8	1·9	3·1	2·2	1·1
Cow pea (*Vigna sinensis*)[33] ...	24·1	...	...	...	...	...
Cow pea[37] ...	24·6	6·9	3·1	6·2	...	0·6
Field bean (*Dolichos lablab*)[33]	23·8	...	...	...	...	...
Field bean[58] ...	26·3	9·2	2·8	8·1	...	0·5
Green gram (*Phaseolus aureus*)[33] ...	22·3	...	...	...	...	...
Green gram[35] ...	28·7	...	...	6·8	...	1·1
Green gram[37] ...	26·8	6·3	2·7	7·0	...	0·4
Green gram (Mung bean)[39]	...	2·6	1·5	3·8	1·4	0·6
Green gram[43] ...	23·6	...	...	...	...	1·0
Green gram[148] ...	24·0	3·4	...	8·2	1·8	1·8
Green gram, strain No. 127[149]	23·3	12·5	4·6	7·2	...	0·6
Green gram, strain No. T-1[149]	24·6	11·3	4·1	6·6	...	0·6
Green gram (Mung bean)[152]	...	3·2	1·6	3·0	...	...
Horse bean or broad bean (*Vicia faba*)[40] ...	...	6·5	2·9	5·5	3·1	0·9

* (C: Chemical; CC: Chromatographic

OF LEGUME PROTEINS

ACIDS							Method of estimation*
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
4·5	0·5	0·9	...	6·7	5·0	3·2	M
4·1	...	0·3	2·9	5·2	2·5	2·7	CC
4·2	...	1·3	5·8	7·4	3·7	4·4	M
...	...	1·4	...	...	...	...	C
...	...	0·8	...	...	...	...	C
...	3·1	1·2	...	...	...	...	C
5·0	0·8	1·7	4·8	8·0	6·0	5·4	M
4·9	...	1·2	2·8	8·2	6·5	5·5	MM
...	...	...	0·6	...	...	...	C
4·3	...	...	0·0	...	...	...	M
4·2	...	...	3·9	...	...	4·0	CC
2·7	...	3·1	4·4	4·9	5·6	3·6	M
3·3	...	2·9	4·6	4·9	3·1	3·9	M
5·5	...	1·4	3·8	6·7	4·6	5·2	M
5·1	...	1·3	3·9	7·7	4·8	5·7	M
...	2·2	1·4	...	...	...	...	C
5·8	...	1·5	3·5	8·9	5·0	6·0	M
5·4	0·7	1·1	4·3	7·2	5·5	6·4	M
...	0·7	0·8	...	...	...	...	C
5·8	...	1·3	4·2	...	...	5·3	CC
4·2	...	2·1	2·9	5·5	4·0	3·2	M
3·8	...	2·0	2·8	5·2	5·0	3·5	M
2·9	0·4	0·5	...	5·0	3·0	3·8	...
...	1·9	1·8	...	...	...	...	C
5·2	0·7	1·0	3·2	7·5	4·9	6·3	M
...	1·3	1·3	...	...	...	...	C
5·3	...	0·7	3·3	8·9	6·0	5·6	M
...	2·2	1·9	...	...	...	...	C
6·0	...	1·2	3·5	8·3	4·8	6·0	M
5·9	0·6	1·0	3·5	7·7	6·3	6·4	M
2·8	0·3	0·6	1·9	9·1	0·3	6·2	M
...	0·4	0·9	...	...	...	...	C
3·1	0·7	1·9	2·0	...	...	3·6	CC
3·7	...	3·2	3·2	8·3	5·1	4·7	M
3·9	...	2·8	2·5	6·8	5·3	4·3	M
...	0·4	...	...	...	...	...	C
3·4	1·1	0·5	2·6	7·6	5·5	5·1	...

M: Microbiological; MM: Miscellaneous).

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Trypto-phan %
Horse gram (*Dolichos biflorus*)[33] ...	21·3	...	...	...	...	...
Horse gram[58] ...	22·8	5·4	3·0	8·3	...	0·6
Horse gram[148] ...	22·0	6·0	...	13·6	2·6	1·9
Horse gram, strain No. 76[149]	23·5	13·9	5·9	5·8	...	0·9
Khesari dhal (*Lathyrus sativus*)[43] ...	28·8	...	...	...	...	1·0
Khesari dhal[58] ...	31·6	7·8	2·5	6·9	...	0·4
Khesari dhal[148] ...	28·0	...	9·1	8·0	1·3	1·1
Khesari dhal[38,151] ...	...	...	...	...	6·0	1·0
Lentil (*Lens culinaris*)[35] ...	29·6	...	...	6·4	...	0·8
Lentil[37] ...	26·6	7·0	2·1	5·8	...	0·3
Lentil[45] ...	...	...	...	5·1	...	0·6
Lentil[148] ...	25·0	...	13·5	11·6	1·8	1·6
Lima bean (*Phaseolus lunatus*), average of 3 varieties[21] ...	20·9	...	...	...	...	...
Lupin seeds, sweet, white (*Lupinus albus*)[53] ...	...	12·1	3·4	3·0	...	1·5
Lupin seeds, unripe (*Lupinus angustifolius*)[10] ...	46·5	...	...	...	...	...
Lupin seeds, ripe[10] ...	43·1	...	...	...	...	...
Lupin seeds, ripe (*Lupinus pilosus*)[10] ...	46·5	...	...	...	...	...
Lupin seeds, ripe (*Lupinus luteus*)[10] ...	79·4	...	...	...	...	...
Navy bean (*Phaseolus vulgaris*)[153] ...	...	9·4	3·0	6·4	...	0·5
Palacio bean (*Phaseolus vulgaris*), defatted[154] ...	41·8	4·7	2·5	6·0	...	1·0
Palacio bean, defatted and cooked[154] ...	42·7	4·7	2·4	5·7	...	1·0
Pea (*Pisum sativum*), average of 7 varieties[21] ...	29·3	...	...	...	...	...
Pea[43] ...	21·7	...	...	...	...	1·1
Pea[58] ...	18·4	17·7	2·7	11·4	...	0·7
Pea[148] ...	19·0	...	17·5	12·8	4·6	2·8
Pea[155] ...	...	7·6	2·4	7·7	...	0·8
Pea[156] ...	...	8·9	1·2	5·0	...	0·7
Pea[157] ...	29·8	8·9	1·2	5·0	...	0·7
Pea, unripe[10] ...	31·8	...	...	...	...	...
Pea, ripe[10] ...	27·4	...	...	...	...	...
Pea, sweet, immature, raw[34]	29·6	6·8	0·9	1·4	...	0·7
Pea, sweet, immature, canned[34] ...	23·6	7·8	1·1	2·2	...	1·0
Pea, sweet, nearly mature, raw[34] ...	27·5	7·3	1·2	3·2	...	0·7
Pea, sweet, nearly mature, canned[34] ...	21·1	8·8	1·4	3·1	...	1·0
Pea (also bean)[158] ...	...	7·0	2·2	6·5	2·8	0·8
Pea (Alaska), var. First and Best[22] ...	22·1	...	...	...	...	...
Pea (Alaska), var. White Canada[22] ...	23·6	...	...	...	...	...

ACIDS							Method of estima-tion
Phenyl-alanine %	Cystine %	Methio-nine %	Threonine %	Leucine %	Isoleucine %	Valine %	
...	2·0	0·7	...	...	...	...	C
8·5	...	0·8	3·8	7·9	6·7	5·4	M
5·3	3·1	10·1	4·0	...	...	6·5	CC
4·3	...	2·0	3·2	9·4	5·1	6·6	M
...	0·7	0·2	...	...	...	...	C
4·1	...	0·4	2·3	6·6	6·6	4·7	M
1·4	1·6	1·6	2·7	...	...	3·3	CC
7·9	1·0	0·6	3·3	7·1	1·9	6·2	...
4·5	...	0·7	3·5	6·9	4·5	5·0	M
4·1	0·8	0·8	2·9	5·4	5·4	5·4	M
4·0	...	0·6	3·0	5·5	5·8	5·1	MM
5·3	4·0	0·7	5·0	...	...	5·6	CC
...	...	1·8	...	...	...	...	C
4·1	...	2·6	2·8	9·1	1·3	2·0	C
...	1·4	0·5	...	...	...	...	...
...	1·8	0·5	...	...	...	...	...
...	1·9	0·7	...	...	...	...	...
...	2·8	0·6	...	...	...	...	...
3·4	...	3·9	3·2	8·2	5·8	6·0	MM
5·4	...	0·7	5·0	13·2	...	5·3	M
5·3	...	0·7	4·8	11·8	...	5·1	M
...	...	1·4	...	...	...	...	C
...	0·5	0·3	...	...	...	...	C
5·8	...	1·3	4·9	10·9	8·4	7·8	M
6·4	0·9	0·9	6·9	...	...	1·3	CC
4·3	0·7	1·8	3·9	6·5	6·3	4·2	C
4·8	1·2	1·0	3·9	6·4	4·1	4·0	MM
4·8	...	0·4	3·9	6·4	4·1	4·0	M
...	0·9	1·0	...	...	...	...	...
...	1·4	1·0	...	...	...	...	...
2·5	...	0·6	4·7	4·7	3·6	3·1	M
2·4	...	1·0	3·0	6·1	4·4	3·4	M
3·0	...	0·8	3·2	7·2	4·7	3·3	M
3·9	...	1·0	3·3	8·8	4·8	3·8	M
5·0	1·3	1–3	3·9	7·0	5·5	5·5	MM
...	2·0	1·0	...	...	...	...	C
...	2·0	1·0	...	...	...	...	C

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Pinto bean (*Phaseolus vulgaris*)[150] ...	20·5	5·4	2·9	6·8	...	1·0
Red gram or Pigeon pea (*Cajanus cajan*)[33] ...	22·2	...	...	...	...	...
Red gram[37] ...	25·9	5·4	3·4	6·4	...	0·2
Red gram[43] ...	22·1	...	...	...	...	0·9
Red gram[148] ...	22·0	7·4	...	10·0	3·3	1·1
Red gram, strain No. C-11[149]	20·3	13·9	5·3	6·1	...	0·8
Red gram, strain No. 37[149]	21·9	12·7	4·8	6·2	...	0·4
Red gram, strain No. 97[149]	23·3	13·1	6·4	5·4	...	0·8
Snap bean (*Phaseolus vulgaris*), average of 5 varieties[21] ...	25·1	...	...	...	...	...

ACIDS							Method of estimation
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
6·2	...	1·0	4·3	8·2	5·7	6·2	M
...	2·7	1·4	...	...	...	...	C
9·1	0·8	0·9	3·4	7·0	5·7	5·1	M
...	0·4	0·3	...	...	...	...	C
8·0	3·7	1·2	5·9	...	...	5·0	CC
7·4	...	3·2	3·4	5·6	5·4	4·5	M
7·9	...	3·4	3·1	6·1	5·1	4·3	M
6·8	...	3·2	2·8	5·6	5·0	3·0	M
...	...	1·8	...	...	...	...	C

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CHAPTER III

SOYA BEAN

SOYA BEAN (*Glycine max*) can be rightly considered to be in a class by itself in that it is intermediary between legumes and oilseeds. It contains more protein (40-45 per cent) than most legumes (Table V) but less fat (20 per cent) than most oilseeds[1]. It is said that as firmly as the history of development of man in the western world is related to bread and meat (animal protein), his history in the eastern world is linked up with millet, rice and soya bean (vegetable protein)[2]. From time immemorial, soya beans have supplied, in the form of soya bean milk, soya-cheese and baked goods, a substantial part of the protein in the diet of the Chinese and other far eastern people[1-6].

During the second world war, soya bean was extremely important in the wartime economy of the Axis powers[2, 7, 8]. It has been reported that the Manchurian production of soya beans alone was sufficient to provide the Japanese population with their daily requirements of 70 grams protein and the production in Japan could meet the protein needs of an additional 6½ million people[2, 6]. With a view to overcoming the critical shortage of protein in their wartime food economy, the Germans developed a high quality soya bean flour, popularly known as 'Edelsoja'[8]. Though considerable quantities were also produced in the United States[2, 6, 9], only a small fraction was used as human food[2] and even this quantity decreased after the war[10]. The chief virtue of soya bean, as a source of dietary protein, lies in its comparative cheapness[1, 2, 11, 12], making its inclusion in low cost diets a feasible proposition[13]. Its potentialities in under-developed countries like Malaya[14], Indonesia[15] and Paraguay[16] have been realized, as also the need for popular propaganda in the Philippines[17] and India[18].

Protein content: The protein content of soya beans and soya bean products is presented in Tables V and VI. Soya beans and high-fat (full-fat) soya bean flour or grits have a protein content of more than 40 per cent, medium-fat flour or grits, more than 45 per cent and low-fat flour or grits, more than 50 per cent[1, 2, 10]. Considerable varietal variation in the protein content of soya beans has been reported[1, 3, 6, 19, 20], but whether environmental conditions and soil fertility have a similar effect is a subject of controversy[1, 19].

Amino acid composition: The amino acid composition of soya bean protein is presented in Table VI. Except for a deficiency of methionine[21-24] and cystine[24-27], soya bean protein is well balanced with respect to the other essential amino acids[21]. Since the availability of methionine[28-30], as well as cystine[24, 26, 28-30] increases with optimal heat

processing, correspondingly the extent of deficiency with respect to these amino acids also becomes less. However, supplementation with methionine increases the protein efficiency of raw, as well as optimally processed soya beans, showing that even the protein in the latter is somewhat deficient in methionine[21]. Optimal heat-processing also increases the rate of enzymic release of essential amino acids[31,32] including methionine[33].

Soya bean protein is a good source of lysine[34,35] and compares favourably with the other legume proteins in this respect. It is also rich in valine[34,35]. Heat-processing inactivates the lysine present in soya bean protein to varying extents[20,36]. Drastic heat-processing brings about the destruction of lysine[23,30,31,37], cystine[30], arginine[31] and tryptophan[31].

Csonka and Jones[38,39] observed considerable variation in the tyrosine, tryptophan and cystine contents of different varieties of soya beans and suggested that selection and breeding may lead to the ultimate development of varieties with a highly balanced amino acid make-up[39]. Recent investigations have, however, failed to reveal any significant varietal variations in the amino acid composition of soya bean proteins[20,36], except for small differences in the methionine[20] and lysine[36] contents.

Nutritive value: Raw soya bean protein possesses a low nutritive value[25,40-44] and this has been attributed to various factors[31,45] including the presence of heat-labile trypsin inhibitor[46-54] and a toxic protein fraction known as soyin[55,56], as well as a type of indigestibility whereby certain amino acids are tied up in the protein molecule in such a way that they cannot be assimilated[3]. The nutritive value of soya bean protein is influenced by the state of maturity[28,57], but not by variety[36,57]; it is further reported to be improved on germination[57].

The proteins present in optimally heat-processed soya bean flour possess a high nutritive value[28,58] which compares favourably with that of milk proteins[44,59-62] and is superior to that of the proteins present in groundnut and cottonseed (*Gossypium herbaceum*) flours[61-63].

The value of soya bean protein in the feeding of infants[64], adults[65] and convalescents[66] and in the treatment of cases of hunger oedema[67,68], malnutrition[69] and kwashiorkor[70] has been demonstrated.

Supplementary value: Being rich in both lysine and valine[34,35], soya bean protein is efficient in supplementing wheat proteins[62,63,71] and is reported to surpass even milk proteins in this respect[61,72,73]. Bread containing soya bean is superior in the quality of its proteins to plain wheat bread[34,35,74,75] and soya bean protein supplements milk proteins in the bread formula[73,76]. Supplementary relationships have also been observed between the proteins of soya bean and those of yellow corn[77-79] and rye[71].

The gross supplementary value of soya bean to the poor rice diet* has not been found to be greater than that of any one of the common legumes when cooked and consumed as a pulse[80]. It has, however, been recently reported that, when optimally heat-processed, soya bean is significantly superior to Bengal gram (chick peas) in its supplementary value to the poor rice diet[81].

The supplementary relationship between soya bean protein and sesame protein is presumably due to the mutual making up of the deficiency of methionine in the former and lysine in the latter[82-84]; this mixture has potentialities for wide application in practical nutrition.

Processing: Soya bean offers the most striking example of a material whose protein value is improved by optimal heat-processing[85]. As early as 1917, Osborne and Mendel observed that while animals fed diets containing raw soya bean grow slowly, heat-processing of the soya bean improves their growth to a remarkable extent[40]. This observation has since been confirmed by a number of workers using the rat[24, 26, 28, 44, 57, 86-93], the mouse[54], the chick[21, 23, 24, 29] or the pig[94] as the experimental animal. Human metabolism studies have shown that the nitrogen retention in adults fed enough soya bean flour to furnish 75 per cent of the protein in their diet is about 20 per cent greater with autoclaved than with raw flour[95]. It has been reported, however, that drastic autoclaving, in contrast to optimal heat-processing, has a deleterious effect on the nutritive value of soya bean protein[23, 28-30, 86, 92, 93].

Since soya bean flour and grits are not consumed as such, but in the form of cooked foods and since overcooking may eventually impair their protein value, it is not usually heated to the extent necessary to obtain maximum nutritional value[2, 28, 91]. In processing soya bean, it is, therefore, customary to prepare a line of flours that have received limited heat treatments depending upon the type of product in which they are to be used[2].

Utilisation: The importance of processing, apart from nutritional considerations, also lies in debittering soya bean products[1, 8, 11, 85, 91, 96], removing their characteristic beany flavour[11, 96, 97] and generally improving their palatability. Several methods of processing soya bean into human food have been described in the literature and among the products, soya bean milk[3-5, 18, 58, 83, 98-100] and soya bean curd[4, 5, 18, 83, 101-103] are the best known. The value of soya bean milk in feeding infants[3, 4, 104-109], particularly those allergic to animal milk[4, 13, 110, 111], has been amply demonstrated. The extraction of protein from soya bean with a view to fortifying different food products has also been advocated[13]. Soya bean sauce and other similar products represent pre-digested protein foods that are both palatable and wholesome[112-118].

* Refers to the diet of the lower income groups in South India; it consists predominantly of polished rice and small amounts of legumes, vegetables, vegetable oil and common salt, but little milk or other foods of animal origin.

Soya bean grits and flour are also finding increasing application in the human dietary[2, 6, 8, 11, 12, 85, 91, 96, 116, 119, 120], chiefly as meat extenders[2, 8, 10-12, 85, 91, 96, 97, 116, 119-122] and in bread[1, 2, 11, 12, 85, 91, 96, 116, 119, 120, 123, 124] and other baked products[2, 10, 11, 12, 85, 91, 97, 116, 119, 120, 125-127], soups[2, 8, 11, 85, 91, 96, 128, 129], paste goods[2, 8, 11, 96, 130] and composite protein foods[131, 132].

TABLE V

NUTRITIVE VALUE OF SOYA BEAN PROTEINS

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Soya bean (*Glycine max*)[15] ...	...	10	...	...	0·8
Soya bean[133] ...	42·4	10	...	...	0·8
Soya bean[134] ...	40·0	10	54·0	76·0	...
Soya bean[135] ...	...	10	...	...	1·3
Soya bean, raw[92] ...	31·2	14	...	...	0·7
Soya bean, raw[136] ...	...	8	55·0	...	...
Soya bean, raw[137] ...	41·2	5	64·0	83·0	0·6
		10	58·0	85·0	1·6
		15	54·0	89·0	1·4
Soya bean, raw[138] ...	...	...	...	...	0·1
Soya bean, raw, dehulled[93]	41·9	11	...	...	0·7
Soya bean, raw, ground[44]	...	18	41·0	85·0	0·4; 0·5
Soya bean, raw, powdered[100] ...	...	10	...	...	1·0
Soya bean, var. Manchurian[80] ...	40·0	10	61·0*	89·3*	0·7*
Soya bean, var. Bengal green[80] ...	41·0	10	48·7*	87·8*	0·8*
Soya bean, var. Lyallpur[80]	32·8	10	66·6*	83·8*	1·2*
Soya bean, var. Kashmir[80]	38·0	10	54·7*	83·3*	0·9*
		10	42·5†	91·0†	...
Soya bean, var. Punjab, sample I[80] ...	42·4	10	63·8*	93·2*	1·1*
		10	59·0†	92·0†	...
Soya bean, var. Punjab, sample II[80] ...	40·4	10	62·3*	90·2*	0·8*
		10	57·3†	92·3†	...
Soya bean, fresh, var. Illini[139] ...	32·9	10	69·1	85·3	...
Soya bean, germinated for 48 hrs.[100] ...	...	10	...	...	1·3
Soya bean, var. Illini, germinated, raw[57] ...	...	10	...	...	1·4
Soya bean, var. Illini, immature, raw[57] ...	...	10	...	...	1·1
Soya bean, var. Illini, mature, raw[57] ...	...	10	...	...	0·5
Soya bean, var. Mansoy, mature, raw[57] ...	...	10	...	...	0·0
Soya bean, var. Dunfield, mature, raw[57] ...	...	10	...	...	0·1
Soya bean, var. Virginia Brown, mature, raw[57] ...	...	10	...	...	0·2
Soya bean, var. Mandarin, mature, raw[57] ...	...	10	...	...	0·2

* denotes steam cooked diet.

† determined by human metabolism experiments.

TABLE V. *Nutritive Value of Soya bean Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Soya bean, var. Manchu, raw[87] ...	38·0	40	...	...	0·6
Soya bean, var. Illini, raw[90]	...	13	49·1	78·0	...
Soya bean, var. Herman, ground, raw[26] ...	...	18	...	...	0·5
Soya bean, var. Illini, ground, raw[26] ...	...	18	...	...	0·4
Soya bean, var. Bansei, vine-ripened, raw[89] ...	...	10	...	...	0·6
Soya bean, var. Funks Delicious, vine-ripened, raw[89] ...	...	10	...	...	0·5
Soya bean, whole, stored for 8 to 9 months[139] ...	...	10	62·6	78·3	...
Soya bean, whole, stored for 13 to 14 months[139] ...	...	10	66·1	80·0	...
Soya bean, whole, stored for 33 to 34 months[139] ...	...	10	56·0	75·0	...
Soya bean, ground, stored for 8 to 9 months[139] ...	...	10	73·7	85·7	...
Soya bean, ground, stored for 13 to 14 months[139] ...	...	10	69·2	84·7	...
Soya bean, ground, stored for 33 to 34 months[139] ...	...	10	64·0	82·8	...
Soya bean, var. Manchurian, baked at 120°C[80] ...	40·0	10	...	...	1·1
Soya bean, dry heated at 120°C for 30 mins.[92] ...	31·2	14	...	...	0·5
Soya bean, dry heated at 120°C for 60 mins.[92] ...	31·2	14	...	...	0·4
Soya bean, dry heated at 120°C for 120 mins.[92] ...	31·2	14	...	...	0·5
Soya bean, dry heated at 120°C for 180 mins.[92] ...	31·2	14	...	...	0·4
Soya bean, ground, dry heated at 135°C for 90 mins.[44] ...	...	18	...	...	0·5
Soya bean, cooked[58] ...	37·2	5	94·5†	90·5†	...
Soya bean, steam cooked[140]	...	...	...	79·9†	...
Soya bean, steamed for 15 mins. at atm. pr.[92] ...	31·2	14	...	...	1·3
Soya bean, steamed for 30 mins. at atm. pr.[92] ...	31·2	14	...	...	1·2; 1·4
Soya bean, steamed for 60 mins. at atm. pr.[92] ...	31·2	14	...	...	1·3
Soya bean, steamed for 120 mins. at atm. pr.[92] ...	31·2	14	...	...	1·2
Soya bean, steamed for 180 mins. at atm. pr.[92] ...	31·2	14	...	...	1·2
Soya bean, steam cooked for 180 mins. and subsequently dried in a current of air at 80-90°C[137] ...	41·2	5 10 15	52·0 50·0 47·0	92·0 90·0 94·0	... ...
Soya bean, autoclaved[45] ...	...	10	...	...	1·5

† determined by human metabolism experiments.

TABLE V. *Nutritive Value of Soya bean Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Soya bean, autoclaved[141] ...	...	...	96·5†	90·0†	...
Soya bean, autoclaved at 15 lb. pr. for 15 mins.[92] ...	31·2	14	...	...	1·3
Soya bean, autoclaved at 15 lb. pr. for 30 mins.[92] ...	31·2	14	...	...	1·3
Soya bean, autoclaved at 15 lb. pr. for 60 mins.[92] ...	31·2	14	...	...	1·0
Soya bean, autoclaved at 15 lb. pr. for 120 mins.[92]	31·2	14	...	...	0·7
Soya bean, autoclaved at 15 lb. pr. 180 mins.[92] ...	31·2	14	...	...	0·3 ; 0·5
Soya bean, autoclaved at 15 lb. pr. for 60 mins.[90]	...	13	67·0	83·1	...
Soya bean, var. Kashmir, autoclaved[80] ...	38.0	10	63·6	91·5	...
Soya bean, var. Punjab, autoclaved, sample I[80]	42·4	10	64·0	94·0	...
Soya bean, var. Punjab, autoclaved, sample II[80]	40·4	10	63·8	94·0	...
Soya bean, var. Manchurian, autoclaved at 120°C[80] ...	40·0	10	...	...	1·5
Soya bean, var. Manchurian, autoclaved at 15 lb. pr. for 60 mins.[87] ...	38·0	40	...	...	0·9
Soya bean, var. Herman, ground and autoclaved at 15 lb. pr. for 60 mins.[26]	...	18	...	...	1·1
Soya bean, var. Illini, ground and autoclaved at 15 lb. pr. for 60 mins.[26]	...	18	...	...	1·0
Soya bean, ground and autoclaved at 17 lb. pr. for 90 mins.[44] ...	...	18	...	...	1·2
Soya bean, ground and autoclaved at 17 lb. pr. in sealed bomb for 90 mins.[44] ...	...	18	...	...	0·9
Soya bean, var. Illini, germinated, autoclaved[57]	...	10	...	...	1·9
Soya bean, var. Illini, immature, autoclaved[57]	...	10	...	...	2·0
Soya bean, var. Illini, mature, autoclaved[57] ...	...	10	...	...	1·7
Soya bean, var. Mansoy, mature, autoclaved[57] ...	...	10	...	...	1·7
Soya bean, var. Dunfield, mature, autoclaved[57] ...	...	10	...	...	2·0
Soya bean, var. Virginia Brown, mature, autoclaved[57] ...	...	10	...	...	1·6
Soya bean, var. Mandarin, mature, autoclaved[57] ...	...	10	...	...	1·6
Soya bean, var. Bansei, vine-ripened, heat-processed[89] ...	...	10	...	...	1·5

† determined by human metabolism experiments.

TABLE V. *Nutritive Value of Soya bean Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value		
			Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Soya bean, var. Funks Delicious, vine-ripened, heat-processed[89] ...	...	10	...	...	1·4
Soya bean cake[140] ...	...	...	...	85·3†	...
Soya bean meal[42] ...	...	5 10	78·0 64·0	... ...	... ...
Soya bean oil meal[62] ...	42·3	10	...	...	2·1
Soya bean meal, raw[33] ...	...	9	53·0	81·0	...
Soya bean meal, raw[88] ...	...	...	49·6	67·0	...
Soya bean meal, heat-processed[33] ...	...	9	71·0	84·0	...
Soya bean meal, heat-processed ('Soma meal')[88]	...	...	63·3	71·0	...
Soya bean meal, var. Illini, expeller-pressed at high temperature (150°C)[26] ...	...	18	...	...	0·8
Soya bean meal, expeller-pressed at low temp. (105°C)[44] ...	... ...	10 18	... ...	... ...	0·7 0·6
Soya bean meal expeller-pressed at medium temp. (130°C)[44] ...	...	18	...	...	1·2
Soya bean meal, expeller-pressed at high temp. (150°C)[44] ...	... ...	10 18	... 51·0	... 87·0	1·2 1·5
Soya bean meal, hydraulic-pressed at low temp. (82°C)[44] ...	...	18	...	...	0·8
Soya bean meal, hydraulic-pressed at medium temp. (105°C)[44] ...	...	18	...	...	1·1
Soya bean meal, hydraulic-pressed at high temp. (121°C)[44] ...	...	18	...	...	1·2
Soya bean meal, expeller-pressed, baked as biscuit[91] ...	49·4 50·0	10 10	... ...	... ...	2·4 2·2
Soya bean meal, expeller-pressed, baked as griddle cake[91] ...	49·4 50·0	10 10	... ...	... ...	1·7 2·1
Soya bean meal, expeller-pressed, baked as pie crust[91]	49·4 50·0	10 10	... ...	... ...	1·6 2·3
Soya bean meal, expeller-pressed, uncooked[91] ...	49·4 50·0	10 10	... ...	... ...	1·7 1·6

† determined by human metabolism experiments.

TABLE V. *Nutritive Value of Soya bean Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Soya bean meal, expeller-pressed, cooked over boiling water for 15 mins.[91]	49·4 50·0	10 10	... ...	... ...	2·6 2·3
Soya bean meal, expeller-pressed, cooked over boiling water for 30 mins.[91]...	49·4 50.0	10 10	... ...	... ...	2·5 2·1
Soya bean meal, expeller-pressed, cooked over boiling water for 60 mins.[91]...	49·4 50·0	10 10	... ...	... ...	2·1 2·1
Soya bean meal, expeller-pressed, cooked over boiling water for 120 mins.[91] ...	49·4 50·0	10 10	... ...	... ...	2·1 2·3
Soya bean meal, solvent-extracted at room temp.[44] ...	...	18	...	...	0.3
Soya bean meal, solvent-extracted, uncooked[91] ...	49·4 50·6	10 10	... ...	... ...	1·8 1·9
Soya bean meal, extracted with cold alcohol[92] ...	49.1	15	...	...	0·6
Soya bean meal, extracted with hexane[92] ...	37·6	15	...	...	0·4; 0·5
Soya bean meal, solvent-extracted at high temp. (98°C)[44] ...	...	18	...	...	1·2
Soya bean meal, extracted with hot alcohol[92] ...	44·9	15	...	...	0·4; 0·5
Soya bean meal, solvent-extracted, heated[24] ...	...	...	...	...	1·6
Soya bean meal, solvent-extracted, heated[138] ...	...	...	...	...	1·4
Soya bean meal, solvent-extracted, heated[142] ...	...	...	61·0; 68·0	84·0	...
Soya bean meal, solvent-extracted, baked as biscuit[91] ...	49·4 50·6	10 10	... ...	... ...	2·0 2·3
Soya bean meal, solvent-extracted, baked as griddle cake[91] ...	49·4 50·6	10 10	... ...	... ...	1·9 2·0
Soya bean meal, solvent-extracted, baked as pie crust[91] ...	49·4 50·6	10 10	... ...	... ...	1·8 1·9
Soya bean meal, extracted with cold alcohol and steamed at atm. pr. for 30 mins.[92] ...	49·1	15	...	...	1·1

TABLE V. *Nutritive Value of Soya bean Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Soya bean meal, extracted with hexane and steamed at atm. pr. for 30 mins.[92] ...	37·6	15	...	...	1·2; 1·4
Soya bean meal, extracted with hot alcohol and steamed at atm. pr. for 30 mins.[92] ...	44·9	15	...	...	1·1; 1·4
Soya bean meal, solvent-extracted, cooked over boiling water for 15 mins.[91] ...	49·4 50·6	10 10	... ...	... ...	2·1 2·9
Soya bean meal, solvent-extracted, cooked over boiling water for 30 mins.[91] ...	49·4 50·6	10 10	... ...	... ...	2·0 2·8
Soya bean meal, solvent-extracted, cooked over boiling water for 60 mins.[91] ...	49·4 50·6	10 10	... ...	... ...	2·2 2·7
Soya bean meal, solvent-extracted, cooked over boiling water for 120 mins.[91] ...	49·4 50·6	10 10	... ...	... ...	2·2 2·1
Soya bean flour[72] ...	...	...	...	...	1·7; 1·8
Soya bean flour[138] ...	...	...	...	...	1·5
Soya bean flour[141] ...	...	...	91·7†	93·9†	...
Soya bean flour[143] ...	...	...	64.0	85·0	1·8
Soya bean flour[144] ...	...	...	...	81·5	...
Soya bean flour[145] ...	...	...	...	85·0†	...
Soya bean flour[146] ...	...	...	...	91·0†	...
Soya bean flour[147] ...	...	...	65·0†	91·9†	...
Soya bean flour, raw[90] ...	42·5	10	59·4	84·8	...
Soya bean flour, edible[118]	...	8	73·0	90·0	...
Soya bean flour, expeller-pressed[61] ...	49·7	9 15	... ...	... ...	2·4 1·7
Soya bean flour, cooked[58]	...	5	91·7†	94·0†	...
Soya bean flour, low-fat[62]	48·7	10	...	...	2·3
Soya bean flour, high-fat ('Edelsoja')[71] ...	45·5	9 11 12 15	... ...	... ...	1·6 1·6 1·5 1·6
Soya bean flour, defatted, unheated[93] ...	52·1	11	...	...	0·8
Soya bean flour, defatted, mildly heat-processed[93]	53·6	11	...	...	1·5

† determined by human metabolism experiments.

TABLE V. *Nutritive Value of Soya bean Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Soya bean flour, defatted, optimally heat-processed[93] ...	54·1	11	...	...	2·0
Soya bean flour, defatted, over heated[93] ...	55·5	11	...	...	1·8
Soya bean flour, partially exploded[90] ...	42·0	10	75·2	95·6	...
Soya bean flour, fully exploded[90] ...	41·8	10	71·2	93·4	...
Soya bean milk[83] ...	4·4	10	...	...	1·9
Soya bean milk[141] ...	...	...	93·9†	89·6†	...
Soya bean milk[149] ...	...	...	...	85·0†	
Soya bean milk[150] ...	...	...	...	80·0†	...
Soya bean milk, commercial[58] ...	...	...	95·3†	89·6†	...
Soya bean milk (from beans germinated for 48 hrs.)[100] ...	...	10	...	...	1·4
Soya bean curd[83] ...	15·0	10	...	...	1·7
Soya bean curd[101] ...	...	3	64·0†	79·0†	...
Soya bean curd[151] ...	...	10	65·0	96·0	...
Soya bean curd, autoclaved[83] ...	...	10	...	...	1·6
Soya bean protein[152] ...	...	...	81·0†	89·0†	...
Soya bean protein, extracted (glycinin)[45] ...	...	10	...	...	1·6

† determined by human metabolism experiments.

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Soya bean (*Glycine max*)[153] ...	...	7·1	2·3	5·8	4·1	1·2
Soya bean[154] ...	...	6·9	2·9	7·5	...	...
Soya bean, raw[83] ...	41·4	...	...	...	...	...
Soya bean, raw[155] ...	37·7	...	...	...	...	...
Soya bean (12 varieties)[39] ...	34.4-47.0	...	...	...	3·9–5.4	1·6–2·1
Soya bean, var. Hawkeye[32]	41·8	7·1	2·4	5·7	...	0·7
Soya bean cake[156] ...	50·8	...	...	...	...	...
Soya bean oil meal[157] ...	...	7·3	2·9	6·8	4·0	1·4
Soya bean oil meal[158, 159] ...	44·8	7·3	2·2	5·7	...	...
Soya bean oil meal, raw[21] ...	43·9	7·4	2·8	6·6	...	1·3
Soya bean meal, expelled[160]	47·5	5·9	2·5	6·7	1·9	1·1
Soya bean oil meal, solvent-extracted[155] ...	46·0	...	...	...	...	...
Soya bean oil meal, solvent-extracted[160] ...	56·9	5·3	3·0	5·3	2·1	1·1
Soya bean flakes, solvent-extracted, var. Acadian[20, 36] ...	48·9	7·8	2·3	6·5	...	1·5
Soya bean flakes, solvent-extracted, var. Arksoy[20, 36] ...	50·9	7·6	2·3	6·5	...	1·5
Soya bean flakes, solvent-extracted, var. A3-176[20, 36]	48·8	7·7	2·3	6·7	...	1·6
Soya bean flakes, solvent-extracted, var. A3K-884[20, 36] ...	47·2	8·1	2·3	6·9	...	1·5
Soya bean flakes, solvent-extracted, var. A4-107-12[20, 36] ...	48·0	8·0	2·2	6·5	...	1·5
Soya bean flakes, solvent-extracted, var. Chief[20, 36]	48·2	7·8	2·3	6·6	...	1·6
Soya bean flakes, solvent-extracted, var. C.N.S.[20, 36] ...	50·8	7·9	2·4	6·0	...	1·6
Soya bean flakes, solvent-extracted var. C-463[20, 36]	47·2	7·5	2·4	6·9	...	1·6
Soya bean flakes, solvent-extracted, var. Earlyana[20, 36]	48·8	7·7	2·3	6·7	...	1·6
Soya bean flakes, solvent-extracted, var. Gibson[20, 36]	48·2	7·5	2·3	6·9	...	1·5
Soya bean flakes, solvent-extracted, var. H-5[20, 36] ...	49.4	7·2	2·2	6·5 ; 6·7	...	1·5
Soya bean flakes, solvent-extracted, var. Lincoln[20, 36] ...	48·9	7·5	2·3	6·7	...	1·6
Soya bean flakes, solvent-extracted, var. Lincoln No. 3[20, 36] ...	46·4	7·7	2·3	6·7	...	1·6
Soya bean flakes, solvent extracted, var. Mamloxi[20, 36]	49.5	8·0	2·4	7·1	...	1·4

*(C: Chemical; M: Microbiological;

ACIDS							Method of Estimation*
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
5·7	1·9	2·0	4·0	6·6	4·7	4·2	MM
5·2	...	1·1	3·3	8·1	7·0	5·6	M
...	1·8	1·1	...	...	...	...	C
...	...	2·0	...	...	...	...	C
...	...	0·5-0·9	...	...	...	...	C
...	0·7	1·0	...	6·6	...	...	M
...	2·0	1·1	...	...	...	...	C
5·3	1·9	1·7	3·9	8·0	6·0	5·3	MM
4·5	...	...	3·3	7·1	4·8	5·2	M
5·1	...	1·3	3·8	7·6	5·1	5·4	M
4·6	...	0·8	4·6	8·4	6·1	5·5	M
...	...	2·2	...	...	...	...	C
4·7	...	1·6	3·7	7·9	6·2	5·3	M
5·0	...	1·4	4·0	7·8	5·3	5·4	M
5·1	...	1·4	3·9	7·9	5·3	5·3	M
5·0	...	1·4	3·9	7·9	5·3	5·4	M
4·9	...	1·4	4·1	7·9	5·4	5·3	M
4·8	...	1·3	3·8	7·9	5·2	5·3	M
5·0	...	1·5	4·0	7·9	5·2	5·4	M
5·1	...	1·3	3·7	7·6	5·2	5·4	M
5·1	...	1·5	4·0	8·0	5·4	5·4	M
5·2	...	1·4	4·0	8·0	5·3	5·3	M
5·1	...	1·4	3·8	8·1	5·4	5·3	M
5·0	...	1·4	3·6	8·0	5·2	5·2	M
5·2	...	1·4	3·9	8·1	5·3	5·4	M
5·2	...	1·5	4·0	8·5	5·4	5·5	M
5·2	...	1·5	3·9	7·9	5·5	5·3	M

MM: Miscellaneous).

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Soya bean flakes, solvent-extracted, var. N-44-92[20, 36] ...	49.0	7.6	2.5	6.7	...	1.5
Soya bean flakes, solvent-extracted, var. N44-774[20, 36] ...	46.4	7.9	2.4	6.7	...	1.6
Soya bean flakes, solvent-extracted, var. Ogden[20, 36]	47.8	7.5	2.3	6.8	...	1.4
Soya bean flakes, solvent-extracted, var. Richland[20, 36] ...	46.4	8.3	2.4	6.5	...	1.6
Soya bean flakes, solvent-extracted, var. Roanoke[20, 36] ...	47.4	7.6	2.5	6.5	...	1.5
Soya bean flakes, solvent-extracted, var. S-100[20, 36]	50.0	7.6	2.5	6.5	...	1.5
Soya bean flakes, solvent-extracted (average of 20 varieties)[20, 36] ...	...	7.7	2.3	6.7	...	1.5
Soya bean flakes, solvent-extracted, toasted (average of 5 varieties)[20, 36] ...	...	7.9	2.4	6.4	...	1.6
Soya bean oil meal, properly heated (4 mins. at 15 lb. pr.)[31] ...	...	7.1	2.7	6.6	...	1.2
Soya bean oil meal, over heated (240 mins. at 15 lb. pr.)[31] ...	...	4.4	2.8	3.2	...	1.0
Soya bean flour, defatted[161]	58.3	7.1	2.3	5.4	...	1.2
Soya bean flour, defatted[162]	...	11.0	3.6	5.9	...	1.1
Soya bean milk[83] ...	4.4	...	...	...	...	...
Soya bean curd[83] ...	15.0	54.9	...	...	...	...
Soya bean protein, whole[163]	...	...	...	...	3.8	...
Soya bean glycinin[143] ...	...	8.3	2.2	5.4	3.9	1.7
Soya bean glycinin[164] ...	...	5.1	1.4	2.7	1.9	1.9–2.8
Soya bean glycinin[165] ...	...	8.1	1.4	9.1	1.9	1.7
Soya bean glycinin[166] ...	...	11.8	3.8	4.4	5.6	...
Soya bean glycinin[167] ...	...	8.1	1.4	9.1	...	1.3
Soya bean glycinin[168] ...	...	5.1	1.4	2.7	1.9	...
Soya bean glycinin (10 varieties)[38] ...	...	...	...	...	3.9–4.6	1.9–2.8

ACIDS							
Phenyl-alanine %	Cystine %	Methio-nine %	Threonine %	Leucine %	Isoleucine %	Valine %	Method of Estima-tion
5·2	...	1·4	4·0	8·2	5·3	5·5	M
5·1	...	1·4	4·0	8·0	5·3	5·2	M
5·3	...	1·3	3·8	8·2	5·5	5·3	M
4·8	...	1·4	3·8	8·0	5·2	5·2	M
5·2	...	1·4	3·9	8·0	5·2	5·2	M
5·1	...	1·4	3·8	8·0	5·3	5·3	M
5·1	...	1·4	3·9	8·0	5·3	5·3	M
5·0	...	1·4	4·0	7·7	5·3	5·3	M
5·2	...	1·4	3·9	7·6	5·1	5·2	M
5·1	...	1·3	3·9	7·8	5·1	5·1	M
5·3	...	0·8	3·9	7·4	4·5	4·6	M
5·1	...	3·6	5·2	7·6	5·7	5·4	MM
...	2·3	1·4	...	...	...	...	C
...	1·2	1·2	...	...	...	...	C
5·2	...	...	...	10·0	2·4	2·6	...
4·3	1·1	1·8	...	9·2	2·4	1·6	...
3·9	0·7–1·5	1·8	...	8·5	...	0·7	...
3·9	1·1	...	...	8·5	...	0·7	...
3·8	...	...	...	9·0	...	1·6	...
...	1·2	...	...	...	...	...	C
3·9	...	...	...	8·5	...	0·7	C
...	0·7-1·5	...	...	...	...	...	C

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CHAPTER IV

OILSEEDS

Oilseeds, in general, form highly potent sources of proteins. They assume special significance because of their abundance in the very regions in which there is high incidence of protein malnutrition[1]. It has been estimated that the annual world production of oilcakes is of the order of 20 million tons[2]. In spite of this, very little of the oilseed proteins find application in human nutrition even at the present time[3, 4]. A fair part is used in a crude form as animal feed[3, 5-9] and the rest is used as manure for crops[3, 5, 10]. The latter use is highly wasteful.

The main reasons for this anomalous position are the following: (1) most of the oilseeds, besides containing high percentages of oil, are also associated with fibre and other constituents which render the seeds difficult to digest by themselves[11, 12]; (2) the oil being the most readily marketable component of the oilseed, little attention is paid to the residue, even though it contains a high percentage of valuable protein[6, 7, 13]; (3) the technique of oil extraction has, so far, been invariably crude and drastic[7] with the result that the protein in the residue is not only denatured to a large extent but also rendered unusable because of its unattractive colour and admixture with a variety of impurities[4, 6, 14]; (4) lack of cheap and easy methods for the extraction and concentration of the proteins and (5) the general impression that oilseed proteins, as a class, are of an inferior type, being deficient in a number of essential amino acids and consequently of a lower order, in nutritive value, than animal proteins.

These impressions are, however, gradually changing. Evidence is increasingly coming to light to show that many of the oilseed proteins are nutritionally of a higher order than was at first supposed and that they can mutually supplement each other to yield balanced combinations[15, 16]. New methods of processing oilseed cakes into human food are also coming to the fore[17, 18] and in course of time, even isolated proteins[19], as also suitable combinations of these, will be available in substantial quantities. With such developments, oilseed proteins are soon bound to assume greater importance in human nutrition[1, 6, 20-23].

Castor Bean (*Ricinus communis*): The kernel contains 23 per cent protein and the expeller-pressed cake from the decorticated seeds, 46 per cent protein[24]. The main protein of castor cake is a globulin[24]. In addition, castor cake contains an albumin, ricin, in a concentration of nearly 1.5 per cent[24]. Ricin has been shown to be highly toxic to man and animals, 0.18 gram, corresponding to 6 castor seeds, being lethal to man[24]. The detoxication of castor bean cake by the hydrolytic decomposition of all the contained proteins has been patented[25].

Other methods have also been developed for destroying ricin[24, 26], but until these methods are shown to be fool-proof and can be applied on a large scale, there is not likely to be much scope for using castor bean protein in animal or human nutrition.

COCONUT (*Cocos nucifera*): Coconut is a poor source of protein as compared with other oilseeds (Table VII), but coconut meal protein itself has a comparatively high biological value[27, 28], particularly if the oilseed is not subjected to high temperatures during the extraction process[7]. Coconut meal protein is not deficient in cystine[29] and is, besides, a fairly rich source of lysine[30, 31] and tryptophan[30], but its methionine content decreases on storage[32]. The gross supplementary value of coconut to rice[33, 34], and tapioca[34] (*Manihot esculenta*) diets has been demonstrated. Coconut flour has been reported to be a satisfactory adjunct to wheat flour in baked products[35].

COTTONSEED (*Gossypium herbaceum*): The vast production of cotton in different parts of the world yields large quantities of cottonseed, the kernel of which can be pressed or extracted to yield a protein-rich meal[1, 4, 8, 36-40]. The protein content of whole cottonseed is 15-20 per cent; of whole cottonseed cake, 25-30 per cent; of dehulled cottonseed kernels, 30-35 per cent; of dehulled cottonseed kernel cake, 40-45 per cent; and of solvent-extracted dehulled cottonseed flour, 55-60 per cent (Table VII).

Amino acid composition and nutritive value: The amino acid composition of cottonseed proteins is presented in Table VIII. The deficient amino acids are lysine[41] and to a lesser extent, methionine[41, 42] and cystine[42]. Marked variations in the availability of individual essential amino acids have been observed in the case of the proteins of cottonseed flour. Although 93 per cent of the arginine is available (to the rat), only 65 per cent of the lysine is available; the values for the other essential amino acids range within these extremes[43]. The methionine in cottonseed protein is, however, reported to be completely available for chick growth[44]. The digestibility of cottonseed meal proteins is low if the hulls are also included in the preparation of the meal[11]. Cottonseed proteins possess a fairly high biological value[45], being slightly superior to groundnut proteins in this respect[38, 46, 47], though inferior to soya bean proteins[38, 39, 47]. They have a definite supplementary value to wheat proteins[38-40].

Detoxication and utilisation: The use of cottonseed meal as animal feed or human food is hampered by the presence of a phenolic constituent, gossypol, which is toxic to non-ruminants[8, 9, 48-51]. Different methods have been employed for its detoxication, all of which involve heat-processing to different extents[9, 36, 52-54]. Cottonseed proteins are quite sensitive to heat injury. Heat-processing has been reported to lower their digestibility[55, 56], as well as their biological value[56-60]. The problem of the cottonseed crushing industry is, therefore, to process

the seeds under conditions drastic enough to detoxify them but not too drastic as to adversely affect the quality of the proteins[9]. Wide variations have been reported in the nutritive value of commercial cottonseed meals, depending on the extent of binding or removal of the gossypol and the extent of heat injury to the protein[9, 61-63].

Carefully prepared cottonseed flour can be used as human food in diverse ways[1, 4, 64]. It has already found wide application as an enriching component in bakery products[4, 38, 40].

GROUNDNUT OR PEANUT (*Arachis hypogea*): Raw groundnut contains 25-30 per cent protein, the expeller-pressed cake, 45-50 per cent protein and the solvent-extracted flour, 55-60 per cent protein (Table VII). Groundnut hearts or germs, frequently separated from the rest of the kernels before processing for edible uses, represent about 2 per cent of the whole kernels by weight and contain 25-30 per cent protein[65].

About 82 per cent of the nitrogen present in groundnut is accounted for by the two globulins, arachin and conarachin, which occur approximately in the ratio of 3:1[66, 67]. Arachin alone, as the sole source of protein in the diet, does not support normal growth in rats[68, 69]. *In vitro* digestion with pepsin and trypsin shows that it is not readily digested[70]. Arachin is deficient in methionine[69, 71-74] and tryptophan[69, 72, 73, 75] and possibly also in threonine[72] and isoleucine[72, 73]. Addition of methionine greatly improves growth on arachin diet and further addition of tryptophan produces even better growth, but still less than that on casein diet, indicating a third deficiency in arachin[69]. Conarachin, on the other hand, is an excellent protein for the growth of rats[69, 73] and is rich in those essential amino acids in which arachin is deficient[67, 72-75]. A mixture of these two proteins in the same proportions in which they occur in groundnut enables animals to grow at a satisfactory rate[69, 72]. We have here an interesting example of protein supplementation within the same seed[67].

Amino acid composition: The amino acid composition of groundnut proteins is presented in Table VIII. The limiting amino acid is methionine[13, 29, 41, 44, 76, 77]. Secondary deficiencies are lysine[41, 77] and possibly also threonine[77] and isoleucine[77]. Methionine[44], as well as lysine[78] present in groundnut proteins has been reported to be almost completely available for chick growth. The availability of all the essential amino acids for the rat is uniformly high in the case of groundnut proteins, ranging from 95 per cent for threonine to 99 per cent for arginine[43].

Nutritive value: In digestibility, the proteins of groundnut compare well with other proteins[5, 79-83]. There are a few reports in the literature to the effect that they are equal to several animal proteins in biological value[69, 77, 84] and superior to certain first class plant proteins like rice proteins[85]. Such reports, however, appear to be exaggerated. In general, groundnut proteins may be regarded on a par with other

oilseed proteins[38, 39, 47], their nutritive value being lower than that of milk proteins[39, 47, 82, 83], meat proteins[81-83] and egg proteins[82, 83]. An interesting observation is to the effect that while at 9 per cent level of protein in the diet, the growth-promoting value of groundnut proteins is somewhat lower than that of the proteins of cottonseed and soya bean flours, at 15 per cent level reverse is the case[39]. As in the case of soya bean, the protein value of groundnut in the raw state is adversely affected by association with a heat-labile trypsin inhibitor[86, 87].

Supplementary value: The supplementary value of groundnut proteins to wheat proteins has been demonstrated by a number of workers[3, 38, 39, 88-90]. As supplement to wheat proteins, groundnut proteins are inferior to skim milk proteins[39], soya bean proteins[39] and meat proteins[90], but superior to cottonseed proteins[39]. Supplementary relationships have also been observed between groundnut proteins on the one hand and oat proteins[91], corn proteins[92, 93] and rice proteins[94, 95] on the other.

Groundnut flour has been shown to supplement poor diets based predominantly on tubers like tapioca and sweet potato[96, 97] (*Ipomeoa batatas*). As for the gross supplementary value of groundnut flour to poor rice diet, the results of experiments with rats[33] and human beings[98] appear to contradict each other.

Processing: The roasting process employed in preparing groundnuts for diverse food uses[65] has no effect on the amino acid composition of the proteins[99] and, unless too drastic, does not alter the nutritive value[7, 81, 90, 100]. The literature on the effect of expeller-pressing on the nutritive value of groundnut meal proteins is somewhat controversial[13, 56, 101]. Controlled heat and steam treatments are reported to enhance the nutritive value of expeller-pressed groundnut meal, in comparison with the unheated and the overheated meals[13, 101]. It has been suggested that the lower nutritive value of the unheated meal may be due both to the unavailability of the sulphur amino acids and to the presence of trypsin inhibitor[13]. In the case of the overheated meal, partial destruction of the sulphur amino acids[87], but not impairment in the availability of lysine[78], is reported to be the contributing factor.

Groundnut flour: Commercial groundnut cake is unsuitable for use as human food because of the impurities and grit generally associated with it[4, 6, 14]. The tannin material in the red cuticle contributes to the bitter taste of groundnut flour prepared from groundnuts which have not been decuticled[65]. If the kernels are carefully selected and the cuticle is removed before pressing, it is possible to obtain a light coloured expeller cake that yields an attractive flour[6, 102, 103]. The groundnut flour itself keeps for at least 5 months[104], but the processed products have been known to keep much longer without any deterioration[105, 106]. Solvent extraction can yield a good edible meal with high keeping quality[14, 107-109].

Human feeding trials: Human feeding trials carried out in different parts of the world have shown that groundnut or its pressed cake (containing less than 10 per cent fat) is well tolerated and easily assimilated at low levels (of 1 to $1\frac{1}{2}$ ounces per day)[23, 110], though some can tolerate even higher levels[5, 79, 110]. There is already evidence to show that groundnuts and groundnut products can relieve conditions of hypoproteinaemia and famine oedema as were encountered in vast areas during the second world war[73]. The value of groundnuts as a concentrated source of dietary protein has been appreciated in various under-developed countries of the world[103, 106, 107, 111-113].

Utilisation: The ideal method of utilisation of groundnut protein as human food would be to produce groundnut protein in a nearly fat-free condition[19] and to utilise it for enriching various types of foods. Till such time as this becomes commercially feasible, the next best procedure would be to use carefully prepared expeller-pressed groundnut flour. This is already being incorporated in a variety of baked products[6] including leavened[3, 22, 89, 110, 114-116], as well as unleavened[23] bread, biscuits[5, 10, 20, 22, 116, 117], pastry[20, 22, 112, 116], soup powders[6, 20, 22, 112, 118], meat products[6], candies[23, 119], malt food[120] and multipurpose food[14, 121]. Incorporation with starchy foods like tapioca to make edible flours[106, 122, 123], fortified grains[102, 124, 125] and macaroni products[106] has also been carried out. Other forms in which groundnut protein can be utilised as human food include groundnut (peanut) butter[20, 119, 126], groundnut milk[113, 127-130], curd[131, 132], sauce[133] and hydrolysate[64, 134, 135].

Linseed or Flax Seed (*Linum usitatissimum*): The proteins in linseed meal possess a fairly high digestibility[11] and biological value[11, 136, 137]. It has been reported that expeller-pressing improves the nutritive value of linseed proteins to a slight extent[56]. Lysine is the principal amino acid deficiency in the protein[138]. It is also deficient in cystine[29, 76], but is an excellent source of tryptophan[139]. Linseed meal is associated with a cyanogenetic glucoside[140] which can be destroyed by dry heat[140], moist heat[140, 141] or even by mere contact with water for some time[142]. Special processing methods should be developed for rendering the meal safe and suitable for human consumption. It has been suggested that the toxicity of linseed meal is also due to the fact that its ingestion produces a deficiency of one or more of the B-complex vitamins[143], particularly pyridoxine[144].

Palm Kernel (*Eloeis guineensis*): Palm kernel cake contains 15-20 per cent protein which by itself is reported to have a nutritive value approaching that of casein[145]. Palm kernel protein is richer in lysine[145] than other oilseed proteins and, as such, would be an ideal supplement to cereal proteins and could also supplement groundnut protein[146].

Poppy Seed (*Papaver somniferum*): The protein contents of different Hungarian varieties of poppy seed vary from 21.4 per cent to 28.0 per cent[147] and of Indian varieties, from 22.3 per cent to 24.4 per

cent[148]. The defatted meal contains 38 per cent protein[148]. The protein possesses a moderate biological value and digestibility[148] and contains useful amounts of the sulphur-containing amino acids[149]. The meal is free from any toxic principle[148] and may lend itself to processing for human food.

Rapeseed (*Brassica napus*): Rapeseed meal has a good protein value[150], but is toxic because of the associated glucoside which gives rise to crotonyl isothiocyanate[140]. The toxic principle is heat-labile[140] and as such, the toxicity of rapeseed meal depends on the degree of heat treatment to which it is subjected during the oil extraction process[150]. Improved methods are needed for detoxifying and processing the meal.

Safflower Seed (*Carthamus tinctorius*): Safflower seeds are edible and are eaten after roasting[151]. The pressed cake, after removal of oil, contains 22-35 per cent protein[12, 151]. It has been reported that with the exception of lysine and valine, safflower seed proteins are richer in the other essential amino acids than casein[12]. There is, however, somewhat contradictory evidence about the biological value of the protein[12, 151, 152]. The digestibility of the protein in some samples of safflower seed cake has also been observed to be low[12]. It is necessary to carry out more exhaustive work both on the acceptability of safflower seed meal as human food and on the nutritive value of its proteins before its potentiality as a source of dietary protein can be correctly assessed.

Sesame Seed (*Sesamum indicum*): Sesame seed contains 20-25 per cent protein[153] and the oilseed cake, 30-48 per cent protein[15, 33, 44, 121]. By itself, sesame protein has about the same nutritive value as groundnut protein[46] and heat-processing is reported to have a deleterious effect[101]. Sesame protein resembles linseed protein in being rich in tryptophan[154] and has, besides, a high methionine content[44, 154, 155]. As such, it is a valuable supplement to vegetable proteins which are normally deficient in these amino acids. Methionine in sesame protein has been found to be completely available for chick growth[44]. The supplementary value of sesame protein to soya bean proteins[155, 156], groundnut proteins[16] and to the mixed proteins of groundnut and soya bean[15] or groundnut and legumes[16] has been demonstrated.

Sesame meal is thus a very useful protein supplement both by itself or in combination with other oilseed meals. Sesame is a common article of food in the dietaries of Egypt[157], China[157] and certain parts of Africa[158]. Sesame meal is already finding application in correcting protein malnutrition in Central America[159]. The main problem is the preparation of an attractive meal free from odour and bitterness[160]. If this can be achieved, there should be considerable scope for extending the use of this valuable source of protein. Protein hydrolysates based on sesame cake also offer possibilities[64].

Sunflower Seed (*Helianthus annuus*): The production of sunflower seed in different parts of the world is steadily increasing[161, 162].

The seed cake obtained after extraction of the oil contains 40-60 per cent protein[7, 44, 161, 163, 164] which, like sesame protein, is rich in methionine[44, 154, 165, 166], though somewhat deficient in lysine[154, 164, 165]. Sunflower seed protein, too, is sensitive to heat injury[56]; when prepared by solvent extraction at low temperatures (less than 75°C), the seed meal contains proteins of fairly high biological value[7]. The digestibility is high[164], being similar to that of milk proteins[154]. Its growth-promoting value is also reported to be high[163], being of the same order as that of animal proteins like casein, lactalbumin and beef protein and superior to that of the proteins of defatted groundnut meal, soya bean, bakers' yeast or blood meal[167]. Sunflower seed protein supplements cereal proteins[21], groundnut protein[168] but not soya bean protein[169]. The flour can be incorporated in bread up to an extent of 20 per cent[21] and can also be used as an enriching component in other baked products[7, 161]. Milk prepared from sunflower seeds has been successfully used in infant feeding[170].

Minor Oilseeds: Recent changes in cultural practices with the tobacco (*Nicotina taubacum*) are expected to make available a considerable quantity of mature tobacco seed for oil extraction[171]. Cold-pressed tobacco seed meal contains about 30 per cent protein, the nutritive value of which is low because of its deficiency in lysine[172]. Different proteins supplement tobacco seed meal proteins to varying extents[172]. In view of the extreme susceptibility of tobacco seed oil to the development of rancidity[173], complete defatting with solvent will probably be necessary before tobacco seed meal can be suitably processed for human consumption.

Edestin, the protein present in fibre hemp seed (*Cannabis sativa*) has a low nutritive value[174, 175], being deficient in lysine[174, 175] and, possibly, also in cystine[174]. Further, it is extremely sensitive to heat injury[175]. Proteins from the pressed cake of the tomato seed (*Lycopersicum esculentum*) supplement corn proteins, though not to the same extent that soya bean or groundnut proteins[93] do. Extracted beech mast kernel (*Fagus sylvatica*) is rich in proteins and has been used as human food in Rumania; it is reported to contain an alkaloid, fagine, toxic only to horses and asses[176]. Kamala seed (*Mallotus philippinensis*) cake is also a rich source of protein but its suitability for human consumption still remains to be ascertained[177].

Coroso oil meal from the Coroso palm (*Acrocomia aculeate*), which grows wild throughout a considerable part of tropical America, has been shown to contain proteins of higher biological value than sesame meal or cottonseed meal[178]. Among African minor oilseeds, the seeds of manketti fruit[179] (*Ricinodendron rautanenii*) grown south of Angola and those of the Egyptian balsam fruit[180] (*Balanites aegyptiaca*) grown in French West Africa are important as potential sources of dietary protein. Manketti seed protein is similar to groundnut protein in nutritive value[179]. Egyptian balsam seed protein is reported to be deficient in lysine, tryptophan, methionine, threonine, isoleucine and valine[180].

TABLE VII

NUTRITIVE VALUE OF OILSEED PROTEINS

SOURCE	Protein content: N×6·25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Coconut, defatted (*Cocos nucifera*)[28, 181] ...	16·2	10	77·2	93·8	1·0
Coconut meal[182] ...	...	5	77·0	...	...
Coconut meal[183] ...	...	10	...	...	1·2
Coconut (copra) meal[184] ...	...	...	69·0	89·0	...
Coconut meal, solvent-extracted at low temp.[7]	20·7	10	70·7	86·1	...
Cottonseed kernel (*Gossypium herbaceum*)[185]	31·8	5	70·5	71·5	...
		10	64·7	77·3	...
		15	53·7	78·3	...
Cottonseed kernel, germinated[185] ...	33·0	10	55·5	78·9	...
Cottonseed meal[11] ...	44·3	8	77·8	80·1	...
Cottonseed meal[47] ...	...	10	...	...	0·9
Cottonseed meal[137] ...	40·9	10	...	...	1·3
Cottonseed meal[184] ...	...	...	81·0	92·0	...
Cottonseed meal[186] ...	...	10	66·0	...	...
Cottonseed oil meal, expeller-pressed[39] ...	45·1	9	...	...	2·1
		15	...	...	1·7
Cottonseed meal, screw-pressed[59] ...	...	...	...	...	0·5-2·3
Cottonseed meal, ether-extracted, raw[57] ...	50·7	13	...	...	2·0
		25	...	...	1·8
Cottonseed meal, extracted[58] ...	64·9; 75·0	10	...	...	2·9; 2·5
Cottonseed meal, solvent-extracted at low temp.[59]	...	...	...	...	2·5
Cottonseed meal, cooked for 26 mins. at a max. temp. of 180°F[58] ...	47·0; 45·3	10	...	...	2·2; 2·5
Cottonseed meal, cooked for 70 mins. at a max. temp. of 180°F[58] ...	46·6	10	...	...	2·2
Cottonseed meal, cooked for 20 mins. at a max. temp. of 200°F[58] ...	44·4	10	...	...	2·3
Cottonseed meal, cooked for 26 mins. at a max. temp. of 200°F[58] ...	44·0	10	...	...	2·3
Cottonseed meal, cooked for 70 mins. at a max. temp. of 200°F[58] ...	45·3	10	...	...	2·0
Cottonseed meal, cooked for 36 mins. at a max. temp. of 230°F[58] ...	46·3	10	...	...	2·0
Cottonseed meal, cooked for 37 mins. at a max. temp. of 230°F[58] ...	48·8	10	...	...	2·0

TABLE VII. *Nutritive Value of Oilseed Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Cottonseed meal, cooked for 20 mins. at a max. temp. of 234°F[58] ...	47·3	10	...	...	1·8
Cottonseed meal, cooked for 76 mins. at a max. temp. of 240°F[58] ...	47·9	10	...	...	1·7
Cottonseed meal, cooked for 20 mins. at a max. temp. of 261°F[58] ...	48·1	10	...	...	1·7
Cottonseed meal, cooked for 40 mins. at a max. temp. of 262°F[58] ...	48·3	10	...	...	1·7
Cottonseed meal, cooked for 100 mins. at a max. temp. of 279°F[58] ...	44·0	10	...	...	0·5
Cottonseed meal, ether-extracted, autoclaved at 17 lb. pr. for 30 mins.[57]	50·7	13 25	... ...	... ...	1·6 1·8
Cottonseed meal, ether-extracted, autoclaved at 17 lb. pr. for 60 mins.[57]	50·7	13 25	... ...	... ...	1·1 1·3
Cottonseed meal, ether-extracted, autoclaved at 17 lb. pr. for 120 mins.[57]	50·7	13 25	... ...	... ...	0·3 0·5
Cottonseed flour, solvent-extracted at low temp.[56]	...	10	61·5	89·7	...
Cottonseed flour, hydraulic-pressed, pre-heated for 120 mins. at 190-240°F[56]	...	10	58·1	84·6	...
Cottonseed protein[188] ...	...	...	91·0*	78·0*	...
Groundnut, raw (*Arachis hypogea*)[81,90] ...	28·3	9	57·8	97·4	...
Groundnut, raw, var. Virginia[100] ...	25·0	10	...	...	1·7
Groundnut, raw, var. Chinese[189] ...	...	...	59·0	95·0	...
Groundnut, roasted at 400-450°F for 30-35 mins.[81, 90] ...	...	9	55·8	96·2	...
Groundnut, var. Virginia, roasted at 160°C for 40 mins.[100]	...	10	...	...	1·7
Groundnut, var. Virginia, roasted at 180°C for 40 mins.[100] ...	...	10	...	...	0·2
Groundnut, steamcooked[79] ...	...	...	...	92·5*	...
Groundnut, var. Virginia, boiled for 40 mins.[100] ...	...	10	...	...	1·8
Groundnut, defatted[28] ...	45·7	10	56·6	90·4	...

* determined by human metabolism experiments.

TABLE VII. *Nutritive Value of Oilseed Proteins*

SOURCE	Protein content: N × 6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Groundnut cake[79] ...	...	...	...	85·8*	...
Groundnut oil meal[47] ...	...	10	...	...	0·8
Groundnut oil meal[92] ...	...	9	...	...	1·5
Groundnut oil meal[184] ...	...	...	72·0	90·0	...
Groundnut meal, decorticated[190] ...	...	10	56·5	93·0	...
Groundnut oil meal, screw-pressed (with slight cooking)[13] ...	48·7	9	41·0; 47·8	91·9; 93·4	0·5
		14	...	...	1·0
		20	...	...	0·9
		29	...	...	0·7
Groundnut oil meal, expeller-pressed[39] ...	50·9	9	...	...	2·0
		15	...	...	1·8
Groundnut oil meal, expeller-pressed, at the end of 4 hrs. (210-246°F)[56]	...	10	56·8	95·7	1·3
Groundnut oil meal, expeller-pressed, at the end of 6 hrs. (210-246°F)[56] ...	...	10	49·8	94·0	...
Groundnut oil meal, expeller-pressed, at the end of 8 hrs. (210-246°F)[56]	...	10	50·5	93·2	1·2
Groundnut oil meal, solvent-extracted at low temp.[13]	45·6	9	43·3; 46·9	86·1; 90·2	...
		16	40·9	88·5	...
		20	...	...	0·8
		22	28.7	88·9	...
Groundnut oil meal, solvent-extracted at low temp.[56]	...	10	60·8	94.8	1·5
Groundnut oil meal (screw-pressed, solvent-extracted and solvent removed by mild heating)[13] ...	53·7	9	43·0	92·7	...
		20	...	...	1·0
Groundnut oil meal (screw-pressed, solvent-extracted and solvent removed by drastic heating)[13] ...	50·0	9	39·4; 42·8	92·3; 93·0	...
		20	...	...	0·8
Groundnut oil meal and hulls[137] ...	39·8	10	...	...	1·5
Groundnut flour[5] ...	...	...	...	86·0*	...
Groundnut flour[82] ...	59·0	...	56·0*	99·0*	...
Groundnut flour[83] ...	62·6	2–5	46·0†	95·0†	...
		10	54·0‡	97·0‡	...
Groundnut protein[188] ...	...	...	83·0*	93·0*	...

* determined by human metabolism experiments.

† determined on adult rats. ‡ determined on growing rats.

Table VII. *Nutritive Value of Oilseed Proteins*

SOURCE	Protein content: N×6·25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Linseed meal (*Linum usitatissimum*)[11]...	39·4	8	77·4	89·6	...
Linseed meal[136] ...	...	8	78·0	...	...
Linseed meal[137] ...	35·5	10	...	...	1.9
Linseed meal, expeller-pressed[56]	...	10	72·2	87·5	...
Linseed meal, solvent-extracted at low temp.[56] ...	...	10	69·2	84·8	...
Poppy seed meal (*Papaver somniferum*)[148]	38·0	10	57·9	81·1	1·5
Poppy seed meal, autoclaved at 15 lb. pr. for 15 mins.[148] ...	...	10	...	...	1·5
Safflower seed cake, extracted, Mysore sample (*Carthamus tinctorius*)[12]	35·2	10	84·9	92·4	...
Safflower seed cake, extracted, Bombay sample[12] ...	21·8	10	86·0	76·5	...
Safflower seed cake, hydraulic-pressed[151] ...	32·1	10	...	...	1·3
Sesame seed, defatted (*Sesamum indicum*)[28, 181]	29·0	10	66·6	85·2	1·0
Sesame meal[184] ...	...	...	71·0	92·0	...
Sunflower seed meal, solvent-extracted at low temp. (*Helianthus annuus*)[7] ...	55·4	10	64·5	94·3	...
Sunflower seed meal, solvent-extracted at low temp.[56] ...	...	10	57·1	93·8	...
Sunflower seed meal, extracted, autoclaved at 20 lb. pr. for 30 mins.[56]	...	10	52·0	91·3	...
Sunflower seed flour, decorticated[169] ...	...	...	...	71·0	...
Tobacco seed oil meal, cold-pressed (*Nicotina taubacum*)[172] ...	30·2	10	51·4	78·0	...

TABLE VIII. AMINO ACID COMPOSITION

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Coconut cake (*Cocos nucifera*)[30] ...	...	7·0	2·7	4·8	...	1·8
Coconut cake[32] ...	20-25	7·0	2·7	4·8	...	1·6
Coconut cake, extracted[191]	20·3	...	...	...	...	...
Coconut globulin[192] ...	...	15·9	2·4	5·8	3·2	Present
Cottonseed (*Gossypium herbaceum*)[193] ...	...	7·4	2·6	2·7	3·2	1·3
Cottonseed cake, extracted[191]	24·2	...	...	...	...	...
Cottonseed meal[44] ...	43·9	...	...	...	...	...
Cottonseed meal[194] ...	...	11·3	2·7	3·5	3·2	1·3
Cottonseed meal[195] ...	40·0	7·5	2·8	3·8	1·5	1·0
Cottonseed meal, commercial[58] ...	...	11·4	2·5	4·4	...	...
Cottonseed meal, defatted[196]	...	13·2	3·6	3·4	...	3·9
Cottonseed meal, solvent-extracted, raw[9] ...	56·8	12·2	2·9	4·4	...	1·2
Cottonseed meal, solvent-extracted, raw[58] ...	64·9; 75·0	11·5; 12·4	2·8; 2·9	4·7; 4·9	...	...
Cottonseed meal, solvent-extracted, steamed for 30 mins.[9] ...	56·8	12·1	2·9	4·5	...	1·2
Cottonseed meal, cooked for 26 mins. at a max. temp. of 180°F[58] ...	47·0; 45·3	12·3; 11·8	2·4; 2·6	4·9; 4·8	...	...
Cottonseed meal, cooked for 70 mins. at a max. temp. of 180°F[58] ...	46·6	12·1	2·9	4·8	...	...
Cottonseed meal, cooked for 20 mins. at a max. temp. of 200°F[58] ...	44·4	12·4	2·9	5·1	...	...
Cottonseed meal, cooked for 26 mins. at a max. temp. of 200°F[58] ...	44·0	12·4	2·6	4·4	...	...
Cottonseed meal, cooked for 70 mins. at a max. temp. of 200°F[58] ...	45·3	12·4	2·6	4·9	...	...
Cottonseed meal, cooked for 36 mins. at a max. temp. of 230°F[58] ...	46·3	12·0	2·7	4·8	...	...
Cottonseed meal, cooked for 37 mins. at a max. temp. of 230°F[58] ...	48·8	11·9	2·5	4·6	...	...
Cottonseed meal, cooked for 20 mins. at a max. temp. of 234°F[58] ...	47·3	11·9	2·8	4·9	...	...
Cottonseed meal, cooked for 76 mins. at a max. temp. of 240°F[58] ...	47·9	12·2	2·7	4·8	...	...
Cottonseed meal, cooked for 20 mins. at a max. temp. of 261°F[58] ...	48·1	11·7	2·7	4·7	...	...
Cottonseed meal, cooked for 40 mins. at a max. temp. of 262°F[58] ...	48·3	11·9	2·6	4·8	...	...

* (C: Chemical; CC: Chromatographic;

ACIDS							Method of Estimation*
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
5·2	1·8	1·8	...	11·3	...	2·4	...
5·2	1·8	0-1·9	...	11·3	...	2·4	...
...	3·9	1·4	...	...	...	...	C
2·1	1·4	...	...	6·0	...	4·2	...
6·8	2·0	2·1	3·0	5·0	3·4	3·7	MM
...	3·7	2·8	...	...	...	...	C
...	...	2·1	...	...	...	...	C
6·0	2·2	1·7	3·0	6·0	4·0	4·8	MM
5·5	...	1·3	2·8	5·5	4·5	4·5	M
5·2	...	1·2	3·9	5·9	3·7	5·0	M
4·2	...	3·5	3·1	6·0	3·9	5·1	MM
5·8	...	1·5	3·6	5·7	4·1	5·0	M
5·3; 5·4	...	1·6; 1·5	3·7; 3·7	6·1; 6·1	3·8; 3·5	5·3; 5·0	M
5·6	...	1·5	3·5	5·8	4·0	4·7	M
5·2; 5·1	...	1·3; 1·2	3·8; 4·2	5·9; 6·1	3·8; 3·8	5·3; 5·5	M
5·0	...	1·7	3·8	5·9	3·6	5·0	M
4·9	...	1·5	3·9	5·8	3·5	5·1	M
5·0	...	1·4	4·3	6·1	4·1	5·1	M
5·1	...	1·4	3·4	6·5	3·6	5·1	M
5·5	...	1·3	4·2	6·3	3·6	5·2	M
5·0	...	1·2	3·6	6·0	3·5	5·2	M
5·1	...	1·4	4·0	6·0	3·3	5·1	M
4·9	...	1·6	3·5	5·9	3·6	5·1	M
5·0	...	1·4	3·7	5·8	3·5	5·1	M
5·1	...	1·4	3·8	6·1	3·6	5·1	M

M: Microbiological; MM: Miscellaneous).

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Cottonseed meal, cooked for 100 mins. at a max. temp. of 279°F[58] ...	44·0	11·7	2·5	4·0	...	...
Cottonseed meal, solvent-extracted, autoclaved at 15 lb. pr. for 10 mins.[9] ...	56·8	12·3	2·9	4·5	...	1·2
Cottonseed meal, solvent-extracted, autoclaved at 15 lb. pr. for 30 mins.[9] ...	56·8	10·7	3·1	4·0	...	1·2
Cottonseed meal, solvent-extracted, autoclaved at 15 lb. pr. for 60 mins.[9] ...	56·8	10·7	3·0	3·9	...	1·2
Cottonseed flour[43] ...	54·1	11·3	2·6	4·2	...	1·5
Groundnut (*Arachis hypogea*)[192] ...	...	9·9	2·1	3·0	4·4	1·0
Groundnut, raw[99] ...	29·9	10·6	2·8	3·9	...	1·1
Groundnut, roasted[99] ...	30·0	8·7	2·8	3·9	...	1·0
Groundnut cake[146] ...	55·0	10·4	5·7	6·0	...	1·8
Groundnut cake, extracted[191] ...	51·2	...	...	...	...	...
Groundnut meal[44] ...	42·7	...	...	...	...	...
Groundnut meal[194] ...	...	11·3	2·1	3·0	4·4	1·0
Groundnut meal, defatted[196]	...	13·8	3·0	3.0	...	2·0
Groundnut meal, ether-extracted[78] ...	...	...	...	3·4	...	...
Groundnut meal, commercially screw-expelled, solvent-extracted and dried at a low temp. under reduced pressure, solvent removed with minimal steam (A)[78] ...	...	...	...	3·3	...	...
Groundnut meal, commercial extraction as in (A) but dried at high temp., solvent removed by heavy steaming[78] ...	...	...	...	3·1	...	...
Groundnut meal (A), dry heated at 150-160°C for 60 mins.[78]	...	...	...	3·2	...	...
Groundnut meal (A), twice soaked in water and dried at 100°C[78] ...	...	...	...	3·2	...	...
Groundnut flour[43] ...	61·0	11·3	2·2	3·2	...	1·2
Groundnut protein[197] ...	...	10·6	2·1	3·4	4·4	2·0
Groundnut globulin (arachin)[74] ...	...	...	...	...	...	...
Groundnut globulin (arachin)[192]	...	13·5	1·9	5·0	5·5	0·9
Groundnut globulin (conarachin)[74] ...	...	...	...	...	...	...
Groundnut globulin (conarachin)[192] ...	...	14·6	1·8	6·0	...	2·1
Linseed (*Linum usitatissimum*)[193] ...	...	8·4	1·5	2·5	5·1	1·5
Linseed meal[44] ...	35·1	...	...	...	...	...

ACIDS							
Phenyl-alanine %	Cystine %	Methio-nine %	Threonine %	Leucine %	Isoleucine %	Valine %	Method of Estima-tion
4·8	...	1·2	4·0	5·7	3·3	5·1	M
5·7	...	1·5	3·6	5·7	3·9	4·7	M
5·4	...	1·4	3·3	5·9	4·0	4·9	M
5·5	...	1·5	3·3	6·0	4·0	4·9	M
5·2	...	1·6	3·4	6·2	3·5	4·8	M
5·4	1·6	1·2	1·5	7·0	3·0	8·0	MM
5·6	...	0·9	2·9	5·0	4·5	5·5	M
4·6	...	0·9	2·6	4·7	4·0	4·9	M
4·6	1·9	0·5	1·6	6.9	...	3·7	...
...	1·5	0·5	...	...	...	...	C
...	...	1·7	...	...	...	...	C
5·1	1·6	1·0	1·6	6·7	4·6	4·4	MM
2·8	...	3·4	2·6	6·7	4·6	5·3	MM
...	...	...	...	...	...	...	C
...	...	...	...	...	...	...	C
...	...	...	...	...	...	...	C
...	...	...	...	...	...	...	C
...	...	...	...	...	...	...	C
5·1	...	1·0	2·7	6·7	3·9	4·6	M
5·4	1·9	1·2	2·9	7·0	4·3	8·0	...
...	1·5	0·7	2·6	...	...	...	C
2·6	1·5	0·7	...	3·9	...	1·1	...
...	2·9	2·1	2·0	...	...	...	C
...	3·0	2·1	...	...	...	...	...
5·6	1·9	2·3	5·1	7·0	4·0	7·0	MM
...	...	2·3	...	...	...	...	C

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Linseed meal[194] ...	...	8·4	1·5	3·0	5·1	1·9
Linseed meal[198] ...	43·4	8·4	1·5	3·3	...	1·5
Palm kernel cake (*Eloeis guineensis*)[148] ...	15·0	11·0	1·8	6·7	...	1·7
Poppy seed cake (*Papaver somniferum*)[149] ...	38·0	9·6	3·4	3·7	3·6	...
Poppy seed globulin[149] ...	97·5	10·4	2·9	2·5	4·7	2·0
Safflower seed cake, extracted, Mysore sample (*Carthamus tinctorius*)[12] ...	35·2	13·5	8·8	5·0	...	...
Safflower seed cake, extracted, Bombay sample[12] ...	21·8	12·6	11·2	5·9	...	...
Sesame seed (*Sesamum indicum*)[155] ...	...	...	...	...	...	...
Sesame seed[193] ...	...	9·2	1·5	2·8	4·3	1·9
Sesame seed[194] ...	...	8·7	1·5	2·8	3·5	1·8
Sesame cake, extracted[191] ...	33·1	...	...	...	...	...
Sesame meal[44] ...	47·8	...	...	...	...	...
Sesame flour, whole, ground[154] ...	...	8·7	1·5	2·8	3·5	1·8
Sunflower seed (*Helianthus annuus*)[193] ...	...	8·2	1·7	3·8	2·6	1·3
Sunflower seed[194] ...	...	8·2	1·7	3·8	2·6	1·3
Sunflower seed meal[44] ...	46·7	...	...	...	...	...
Sunflower seed meal, defatted[196] ...	...	11·3	3·0	3·0	...	2·4
Sunflower seed meal, solvent-extracted[154]	...	8·2	1·7	3·8	2·6	1·3
Minor Oilseeds						
Egyptian balsam seed cake (*Balanites aegyptiaca*)[180]	50·0	4·5	1·8	5·2	1·8	0·9
Hemp seed globulin or edestin (*Cannabis sativa*)[199, 200]	...	16·7	2·5	2·4	4·3	1·2
Niger seed kernel (*Guizotia abyssinica*)[201] ...	28·1	10·8	...	4·1	2·4	...
Tobacco seed globulin (*Nicotina taubacum*)[199, 200]	...	16·1	2·2	1·6	4·1	1·5

ACIDS							Method of Estimation
Phenyl-alanine %	Cystine %	Methio-nine %	Threonine %	Leucine %	Isoleucine %	Valine %	
5·4	1·9	2·3	4·0	5·3	4·2	5.1	MM
5·2	...	0·8	3·0	5·3	4·2	5·1	M
...	1·7	1·2	...	5·5	...	4·4	...
3·4	2·0	2·1	3·7	...	...	5·9	CC
4·1	2·0	2·3	4·2	...	...	7·1	MM
4·6	5·8	6·6	21·2	...	14·3	4·5	CC
4·9	5·2	6·4	23·9	...	12·0	4·4	CC
...	2·7	3·4	...	...	...	...	C
8·3	1·3	3·1	3·6	7·5	4·8	5·1	MM
8·0	1·3	3·2	4·0	7·5	4·8	5·1	MM
...	3·4	1·8	...	...	...	...	C
...	...	3·4	...	...	...	...	C
8·3	1·3	3·1	3·6	7·5	4·8	5·1	MM
5·4	1·3	3·4	4·0	6.2	5·2	5·2	MM
5·0	1·4	3·4	4·0	6·7	5·7	5·3	MM
...	...	3·9	...	...	...	...	C
5·0	...	3·4	3·4	6·8	5·1	5·6	MM
5·7	1·6	3·4	4·0	6·2	5·2	5·2	MM
2·9	1·8	1·7	2·0	3·8	2·8	2·5	MM
5·5	1·3	2·2	3·1	7·4	4·7	6·6	M
3·2	1·4	1·4	2·8	4·6	1·9	2·1	CC
5·7	1·1	2·2	4·2	10·5	5·3	6·7	M

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CHAPTER V

NUTS

EDIBLE nuts are useful sources of proteins in our dietary[1, 2], although some of them are quite costly and can be consumed only in small quantities because of their high oil content[3]. On the basis of their high protein content, the oil-bearing nuts have been considered to be equivalent to meat in nutrition; in other words, nuts have been proposed as adequate meat substitutes[4, 5]. This alleged nutritional equivalence is based more on chemical composition than on the actual nutritive value of the proteins[4]. The biological values of the proteins in Brazil nut (*Bertholettia excelsa*), almond (*Prunus amygdalus*), filbert nut (*Corylus avellana*), walnut (*Juglans regia*) and pecan nut (*Carya pecan*) fall within the range 50-60 per cent at 9 per cent level[4, 6] (Table IX). Cashew nut (*Anacardium occidentale*) protein is a prominent exception, possessing a biological value of 72 per cent, only slightly below that of beef protein, 76 per cent[4]. In biological value and digestibility, nut proteins are, as a class, inferior to beef protein[4, 6]. While the difference in biological value between beef protein and the proteins of nuts other than cashew nut is of the order of 25 to 50 per cent[4, 6], the difference in digestibility is not great[4] except in the case of pecan nut proteins which possess a digestibility of only 71 per cent[6] and walnut proteins which possess a digestibility of 84 per cent[4]. The low digestibility of nut proteins in general and pecan nut proteins in particular was observed as early as 1903 in the course of human metabolism studies on Californian fruitarians[7].

ALMOND (*Prunus amygdalus*): From time immemorial, almond has been in the front rank among edible nuts and is always in great demand[1]. The quantities of almond that enter world commerce are higher than those of any other nut, the largest producers being the Mediterranean countries, California, Australia and South Africa[1]. In India, it is greatly valued as a concentrated food; it is reputed to impart vigour and stamina to persons who consume it and is specially recommended for use by athletes. It is used in Indian systems of medicine for the rapid restoration of health in the case of convalescents. Although almond protein has a fairly high digestibility, strangely enough its biological value is comparatively low, being of the order of only 50 per cent[4]. Moreover, apart from its high arginine content, there is nothing striking in the amino acid make-up of amandin, the chief protein of almond[8]. The supplementary value of almond protein to different diets has not been systematically worked out. It is stated to be a good supplement to milk, but the significance of this is not yet clear. Almond milk itself is a French delicacy which is believed to

possess medicinal properties[1]. Its value in infant feeding has been amply demonstrated[9]. The protein and sulphur-containing fragments of almond milk are reported to be utilised by healthy infants to the same extent as those of cow's milk[10].

BRAZIL NUT (*Bertholettia excelsa*): Brazil nut is a native of the Amazon basin[1, 3, 5] and although the largest producer, as the name itself implies, is Brazil, it has also been successfully grown in other parts of the humid tropics, notably in Malaya, Ceylon, Java and the West Indies[1]. Brazil nut is also known in Brazil as the Para chestnut and in the United States, as the butternut[5]. In 1935, some 50,000 tons of the nuts are reported to have been gathered in the Amazon belt[5]. In some years, the export from Brazil has been more than 300,000 tons[1]. In view of its universal appeal and general excellence, Brazil nut has been styled by some, 'The King of Nuts'[1]. It is also known as vegetable meat in Brazil where it is held in esteem on account of its high nutritive value[11]. Brazil nut contains about 15 per cent protein[12, 13] and more than 4 times as much fat[5, 12, 13]. Brazil nut protein is an extremely rich source of methionine[14]; Brazil nut is reported to contain three times as much methionine as any other nut that has so far been studied[15]. Excelsin, the chief globulin of Brazil nut, is low in lysine and valine[8]. Brazil nut protein possesses a moderate biological value[4], but a high digestibility[4] and a growth-promoting value which is only 6 per cent inferior to that of milk protein[16]. In the Amazon belt, Brazil nuts are considered indigestible because of their high fat content[3] and only limited quantities are consumed[3, 5]. This difficulty can, however, be overcome by partial or complete extraction of the oil[12]. Brazil nut flour can be used for many culinary preparations and has been recommended as an excellent supplement especially for school children, soldiers and for pregnant and nursing women[12].

CASHEW NUT (*Anacardium occidentale*): Cashew nut is also a native of the Amazon valley[1, 17] and is esteemed as a dessert nut not only in Brazil and other parts of the tropics, but also in the United States and European countries.[1] The bulk of the world's supplies of cashew nuts comes from the west coast of India and East Africa; smaller quantities are produced in Egypt, the West Indies and Haiti[1]. As has been already pointed out, cashew nut protein is exceptional among nut proteins in possessing a high biological value and digestibility[4, 17-19]. It has also been reported to promote good growth in rats[19, 20]. The chief protein of cashew nut, anacardein, has been analysed for constituent amino acids both by the classical chemical methods[21], as well as by chromatography[22]. Methionine, present to the extent of 1.3 per cent only, seems to be the limiting amino acid[22].

CHINESE TALLOW NUT (*Sapium sebiferum*): Chinese tallow nut protein is deficient in lysine and methionine[23]. Feeding experiments have confirmed these amino acid deficiencies and have shown the

absence of any toxic factors in Chinese tallow nut flour[24]. It has been reported that when supplemented with lysine and methionine, the protein becomes slightly superior to egg albumin in nutritive value[24]. Chinese tallow nut flour has been recommended as an ingredient for the enrichment of wheat flour in the baking industry[23, 24].

Filbert Nut (*Corylus avellana*): Cultivated filbert nuts are closely related to the wild hazel nut (*Corylus colurna*) and the present annual production in the United States is estimated to be 7000-8000 tons, about 85 per cent from Oregon and 15 per cent from Washington[25]. Filbert nuts are also widely cultivated in Kent[2]. The globulins prepared from Barcelona and Du Chilly varieties of filbert nuts are rather well balanced for a plant protein[26]. As compared to casein, the globulins are high in arginine and cystine and low in lysine and methionine[26]. Feeding experiments with rats have confirmed the deficiency of filbert nut protein in these two amino acids[26]. Filbert nut protein possesses a moderate biological value and a high digestibility[4].

Pecan Nut (*Carya pecan*): The pecan is a North American native which grows well as far south as Mexico[5]. In 1944, over 150 million pounds of pecan nuts are reported to have been produced in the United States[1]. As already pointed out, pecan nut protein possesses a moderate biological value[4, 6] and a low digestibility[4, 6, 7]. For producing the same gain in weight in rats, digestible nitrogen from pecan nut is 80 per cent as efficient as that from beef[6].

Minor Nuts: Minor nuts which are reported to be of nutritional importance in Brazil[17] include the Sapucaia nut (*Lecythis usitata*), pine nut (*Araucaria angustifolia*) and rubber seed (*Hevea brasiliensis*). Other minor nuts common in the tropics[1] are the Macadamia or Queensland nut (*Macadamia ternifolia*), oyster nut (*Telfairea pedata*) and Java almond (*Canarium commune*).

Among the nuts of the temperate regions, the walnut (*Juglans regia*) enjoys immense popularity[2]. Walnut protein possesses a moderate biological value and rather a low digestibility[4]. Though the black walnut (*Juglans nigra*), generally grown for lumber in the United States, is rich in protein, its potentiality as human food still remains to be assessed[27]. The sweet chestnut[2] (*Castanea sativa*) and the water chestnut[28] (*Trapa bispinosa*) are comparatively poor sources of protein. Water chestnut protein, however, has a high growth-promoting value[28].

TABLE IX

NUTRITIVE VALUE OF NUT PROTEINS

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Almond (*Prunus amygdalus*)[4] ...	21·9	9	50·8	94·0	...
Brazil nut (*Bertholettia excelsa*)[4] ...	16·3	9	54·1	95·7	...
Cashew nut (*Anacardium occidentale*)[4] ...	19·5	9	72·5	96·2	...
Cashew nut[19] ...	20·9	...	77·2	93·3	...
Cashew nut, defatted[18] ...	31·8	10	72·2	90·4	...
Filbert nut (*Corylus avellana*)[4] ...	13·5	9	50·3	91·3	...
Pecan nut (*Carya pecan*)[4, 6] ...	11·3	9	59·8	70·7	...
Walnut, English (*Juglans regia*)[4] ...	21·2	9	55·9	84·1	...
Water chestnut (*Trapa bispinosa*)[28] ...	8·0	7	...	...	1·8

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Almond albumin (*Prunus amygdalus*)[29] ...	...	10·8	2·2	5·7	3·1	1·3
Almond globulin, amandin[8]	...	11·9	1·6	0·7	1·1	Present
Almond globulin[29] ...	...	9·7	2·0	3·7	3·6	1·7
Brazil nut globulin, excelsin (*Bertholettia excelsa*)[8] ...	...	16·0	1·5	1·6	3·0	Present
Cashew nut globulin (*Anacardium occidentale*)[21]	...	10·7	2·8	1·3	6·8	...
Cashew nut globulin[22] ...	...	10·3	1·8	3·3	3·2	...
Chinese tallow nut protein (*Sapium sebiferum*)[23] ...	...	16·6	2·9	2·6	3·7	...
Filbert nut globulin (*Corylus avellana*), var. Barcelona[26] ...	...	14·4	2·4	2·1	3·3	1·5
Filbert nut globulin, var. Du Chilly[26] ...	...	14·5	2·0	2·0	3·2	1·5
Minor Nuts						
Acorn glutelin (*Pasania cornea*)[8] ...	...	18·2	3·0	4·7	1·8	1·3
Cohune globulin (*Orbignya cohune*)[8] ...	...	17·2	1·7	7·4	...	...

* (C: Chemical; CC: Chromatographic;

ACIDS							Method of Estimation*
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
...	0·9	0·8	...	...	...	...	...
2·5	...	...	...	4·5	...	0·2	...
...	0.8	0·7	...	...	...	...	...
3·6	0·0	...	...	8·7	...	1·5	...
...	1·0	...	...	...	...	...	C
4·4	1·0	1·3	2·8	...	...	4·5	CC
...	1·3	1·6	...	7·4	...	7·8	...
3·8	2·2	0·8	5·3	10·0	5·1	3·7	M
3·5	2·5	0·8	5·6	6·1	5·0	3·4	M
...	2·4	...	...	...	...	...	...
...	0·8	...	...	...	...	...	...

M: Microbiological).

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CHAPTER VI

FRUITS, TUBERS AND VEGETABLES

FRUITS

FRUITS do not contribute materially to the protein content of human diets. As such, reports in the literature on the nutritive value and amino acid composition of fruit proteins are comparatively few.

Based on a study of the free amino acid content of a large number of fruits[1], it has been reported that none of them contains tryptophan, phenylalanine, methionine or valine in the free state; lysine could be detected only in custard apple (*Annona squamosa*) and leucine and isoleucine only in ripe banana (*Musa sapientum*). Dean[2,3], using plant protein diets based on cooked banana for the treatment of kwashiorkor in Africa, found banana to be low in total protein and this, in its turn, to be deficient in methionine. On the other hand, the proteins from three Indian varieties of banana have been reported, on the basis of paper chromatographic analysis, to be richer than casein in a number of essential amino acids, notably cystine and histidine[4].

The isolated protein from Baldwin apples (*Malus sylvestris*) is reported to have a nitrogen content of only 8.5 per cent, of which 93.5 per cent is amino nitrogen[5]. Fifteen amino acids account for 86.3 per cent of the amino nitrogen[5]. Tryptophan could not be detected[5]. The biological value and the digestibility of the proteins of edible portions of green (immature) palmyra fruit (*Borassus flabellifer*) are higher than those of the ripe fruit proteins[6].

TUBERS

Among the tubers, the nitrogenous constituents of only the potato (*Solanum tuberosum*) have been investigated in detail. The nitrogen content of different varieties of potato has been reported to vary from 1.2 per cent to 2.0 per cent on the dry weight basis[7,8]. Of the total nitrogen, 36 per cent to 63 per cent is non-protein[7]; only a fifth of this represents the free amino acids, the balance being equally shared by amides and nitrogenous bases[7,8]. It has been observed that adults can be maintained in nitrogen equilibrium and in good health for long periods with potato as the sole source of dietary protein[9]. Total proteins of the whole potato are only slightly inferior to milk proteins in growth-promoting value[10]. Drying at 40°C has no adverse effect on the nutritive value of potato proteins[10], while cooking increases their digestibility[11]. It has been suggested that protein recovered from starch factories would be a valuable addition to our stock of dietary protein[11]. The chief protein of potato is the heat-coagulable globulin known as tuberin[8,10-12]. Tuberin possesses a fairly high nutritive value[13],

being superior to wheat proteins[10], but distinctly inferior to casein[10, 11]. The non-protein nitrogen fraction in the potato press juice, after separation of the tuberin, is incapable of supporting growth by itself[8, 10, 12]. However, a mixture of this fraction with tuberin in the proportion as present in the whole potato raises the growth-promoting value to a level approximating to that of tuberin, though not to the level of the nitrogenous mixture in the intact tuber[8, 12]; this clearly indicates the existence of a supplementary relationship between the protein and non-protein moieties[8, 10, 12]. The amino acid composition of these two fractions does not, however, indicate the possibility of such supplementation[8, 12]. Though potato protein is deficient in cystine[14, 15] and in methionine[8, 12, 15, 17] and possibly also in histidine[15], it is quite rich in lysine[8, 12, 16, 17]; as such, it should prove a good supplement to cereal proteins. The protein efficiency ratio of potato is reported to decrease on storage, more so at room temperature than at 5°C[8]. Further, the nutritive value of the protein in whole potato is less than that of the protein in peeled potato with the outer cortex removed[8].

Among other tubers that have been investigated, colocasia (*Colocasia esculenta*) and the elephant yam (*Amorphophallus campanulatus*) have about the same protein content as potato[17]. While proteins from these sources resemble potato protein in being deficient in methionine, colocasia protein has a further resemblance in also being rich in lysine[17]. Tapioca,[17-23] otherwise known as cassava or bitter manioc (*Manihot esculenta*) and sweet potato[17, 21, 22] (*Ipomeoa batatas*) are comparatively low in protein, though the protein content differs with the variety[17, 24]. Attempts have been made to evolve hybrids of superior protein content by crossing a variety of tapioca containing 10 per cent protein with the ordinary varieties[24]. Tapioca resembles potato in that nearly half its total nitrogen is non-protein nitrogen[19]. The non-protein fraction has a high lysine content[19]. There is considerable variation in the amino acid composition of tapioca protein as reported by different workers[17, 19, 23, 25]. According to one report, tapioca protein is devoid of methionine[25]. Sweet potato protein has a fairly high biological value[26] and valine content[17, 27] and generally resembles potato protein in amino acid composition[17, 27]. A variety of sweet potato from Bombay has been reported to contain more than 2.5 times the protein present in a variety from Coonoor (India) and (on an equal protein basis), to be richer in arginine, phenylalanine, methionine and valine but not in other essential amino acids[17].

VEGETABLES

Although vegetables are valued in nutrition mainly for their vitamins and minerals, they also contribute, in varying measure, to the protein pool of human diets[28]. However, little attention has been paid to vegetables as a source of dietary protein[29], probably due to the fact that the

bulk that has to be ingested to provide sufficient protein from this source would be excessive and beyond the range of practical dietetics[28].

The relative annual yields of proteins from vegetables and cereals in Kg. per hectacre have been estimated to be as follows[29]: mountain spinach (*Spinacia oleracea*), 875; mangold (*Beta vulgaris macrorhiza*), 860; green cabbage (*Brassica oleracea capitata*), 476; corn, 301 and winter wheat, 244. This clearly shows that the return of protein from leafy vegetables is particularly high.[29]

Protein content: The protein content of vegetables varies widely from species to species[27, 29-32]. Thus, unripe legumes with and without pods contain on the fresh weight basis 2.1 per cent protein; leafy vegetables, 1.7 per cent; leeks, 1.1 per cent; flower and stem vegetables, 0.8 per cent; root vegetables, 0.6 per cent and fruit vegetables, 0.4 per cent, the average working to about 1.1 per cent[29]. In general, leafy vegetables are richer sources of protein than other classes of vegetables except the leguminous group[27, 29, 31, 33, 34]. The variations within the groups are relatively large for the leafy, leek, flower and stem vegetables, but small for the root and fruit groups[29]. Cress,[35] also known in Argentina as 'quimpi' or 'quimpe' (*Coronopus pinnatifidus; Coronopus didymus*) and water cress[32] (*Roripa nasturtium aquaticum*) have a high protein content, as also sesbania leaves[36] (*Sesbania grandiflora*) and drumstick leaves[36] (*Moringa oleifera; Moringa pterygosperma*).

A considerable proportion of the total nitrogen of vegetables is contributed by non-protein constituents including free amino acids, amides, nucleic acids and alkaloids[29]. The ratio of non-protein nitrogen to total nitrogen varies widely between 9 per cent and 68 per cent depending on the type of vegetable[29, 33, 37]. This ratio is reported to be of the order of 31 per cent in leafy vegetables, 41 per cent in leeks, 46 per cent in unripe leguminous vegetables, 47 per cent in flower and stem vegetables, 57 per cent in fruit vegetables and 61 per cent in root vegetables, the average being 42 per cent[29].

Amino acid composition: Ever since Chibnall reported the presence of indispensable amino acids in adequate amounts in the proteins of the vascular, cytoplasmic and chloroplastic portions of spinach[28], the amino acid composition of the proteins in different vegetables has been widely investigated (Table XII). Except for a deficiency in methionine, the proteins of leafy vegetables are well balanced with respect to the other essential amino acids[27, 31, 34, 38]. Drumstick leaf protein is rich in cystine[31], while spinach protein is rich in lysine[27]. The non-protein nitrogen fractions of fenugreek leaves (*Trigonella foenumgraecum*), and celery (*Apium graviolens*) are rich in phenylalanine, while that of the former is also rich in lysine[37].

Generally speaking, the proteins of non-leafy vegetables are deficient in lysine and isoleucine[39]. The proteins of garden peas (*Pisum sativum*) have been shown by feeding experiments to be low in cystine[14].

Cauliflower (*Brassica oleracea botrytis*) protein is well balanced except for slight deficiencies in lysine, leucine and isoleucine[39]. Broccoli[27, 39] (*Brassica oleracea botrytis*) and sweet corn[39] (*Zea mays saccharata*) proteins are deficient in many essential amino acids, while carrot (*Daucus carota*) protein[39] is deficient in all of them. A mixture of broccoli, cauliflower and sweet corn would contain proteins balanced in respect of all the essential amino acids except lysine and isoleucine[39]. Jack seed[31] (*Artocarpus heterophyllus*) protein is relatively low in arginine, histidine and methionine, while the proteins of okra[31] (*Hibiscus esculentus*), brinjal[31] (*Solanum melongena*) and drumstick bean[31] are, in addition, also low in lysine, tryptophan and isoleucine. Green plantain[17] (*Musa paradisiaca*) protein is deficient in methionine but is exceptionally rich in histidine. The non-protein nitrogen fractions of cauliflower[37], field bean[37] (*Dolichos lablab*) and kohlraby[37] (*Brassica oleracea caulorapa*) are rich in cystine, while that of drumstick bean[37] is rich in valine.

Nutritive value: The availability of proteins from 24 kinds of Chinese leafy vegetables is reported to be high, ranging from 86 per cent to 99 per cent[40]. The biological values of the proteins of cabbage[26], amaranth[41, 42] (*Amaranthus gangeticus*), sesbania leaves[43] and ipomoea leaves[42] (*Ipomoe areptans*) are fairly high, whereas that of drumstick leaves[42] is low.

As regards non-leafy vegetables, while the proteins of brinjal[42] possess a fairly high nutritive value, those of cluster beans[43] (*Cyamopsis tetragonoloba*) and green papaya[44] (*Carica papaya*) possess a low nutritive value. The biological value of 'ladies fingers' (*Abelmoschus esculentus*) is high[42] at 5 per cent level of intake but quite low[44] at 10 per cent level.

Supplementary value: Several dehydrated vegetables, when used at the level of 5 per cent in the diet, are reported to be excellent supplements to the proteins of milled wheat flour and milled white corn meal[32]. For this purpose, the proteins of dried mustard greens (*Brassica juncea*) and water cress are better than those of spinach, cauliflower, lettuce (*Lactuca sativa*) and green beans (*Phaseolus vulgaris*)[32].

The supplementary value of amaranth proteins to the proteins of wheat, jowar, bajra and Bengal gram (chick peas) and to the mixed proteins of different cereals and legumes has recently been demonstrated[45]. As supplement to cereal and legume proteins, amaranth proteins are superior to the proteins of other leafy vegetables such as sesbania leaves, drumstick leaves and 'parpukeerai' (*Portulaca oleracea*).[45]

The proteins of okra, which is reported to be extensively used in Egypt to substitute fenugreek in corn bread, have been observed to be better supplements to corn proteins than those of fenugreek itself or cottonseed flour[46].

TABLE XI

NUTRITIVE VALUE OF FRUIT, TUBER AND VEGETABLE PROTEINS

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Nutritive Value: Coefficient of true digestibility %	Nutritive Value: Protein efficiency ratio
Fruits					
Palmyra fruit, green (*Borassus flabellifer*)[6] ...	7.0	3	62.6	80.0	...
Palmyra fruit (ripe) juice, dried[6] ...	4.2	3	52.2	76.8	...
Tubers					
Potato, whole (*Solanum tuberosum*)[47] ...	...	5 8	68.5 67.0	... ...	... ...
Potato, whole, fresh[10] ...	...	10	...	...	1.9
Potato, whole without skin, fresh, var. King Edward[8] ...	11.8	10	...	...	2.0
Potato, whole, without skin, stored, var. King Edward[8] ...	12.8	10	...	...	1.3-1.5
Potato, whole, steamed, with skin, var. King Edward[8] ...	10.8	10	...	...	1.5
Potato, steamed, without skin, var. King Edward[8]	10.4	10	...	...	1.6
Potato, steamed, without skin and outer cortex, var. King Edward[8] ...	10.2	10	...	...	1.8
Potato, whole, dried[10] ...	...	10	...	...	1.9
Potato, dried, without skin, var. King Edward[8]	12.1	10	...	...	1.8
Potato juice, concentrated, from var. King Edward[8]	...	10	...	...	1.5
Potato globulin (tuberin)[8]	...	10	...	...	1.8
Potato globulin (tuberin)[10]	...	10	...	...	1.6
Potato globulin (tuberin)[13]	...	8 10 12	71.0	... ...	2.0 1.7 1.7
Sweet potato (*Ipomeoa batatas*)[26] ...	...	...	72.0	57.0	1.5
Vegetables, leafy					
Leafy vegetable (Chinese, 24 kinds)[40] ...	...	...	...	86.3-99.1*	...
Amaranth leaves (*Amaranthus gangeticus*)[41]	...	10	66.8	84.6	...
Amaranth leaves[42] ...	29.1	5	72.0	78.0	...
Cabbage (*Brassica oleracea capitata*)[26] ...	...	...	76.0	64.0	0.9

* denotes availability of protein.

TABLE XI. *Nutritive Value of Fruit, Tuber and Vegetable Proteins*

SOURCE	Protein content : N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Drumstick leaves (*Moringa oleifa*)[12] ...	26·9	5	41·0	77·0	
Ipomoea leaves (*Ipomoea reptans*)[12] ...	29·3	5	67·0	85·0	...
Sesbania leaves (*Sesbania grandiflora*)[13] ...	31·9	5	64·0	85·0	...
Vegetables, non-leafy					
Brinjal (*Solanum melongena*)[42] ...	14·0	5	71·0	75·0	...
Cluster beans (*Cyamopsis tetragonoloba*)[43] ...	19·5	5	51·0	73·0	...
Ladies fingers (*Abelmoschus esculentus*)[42] ...	14·9	5	82·0	70·0	...
Ladies fingers[44] ...	21·7	10	42·5	84·5	...
Papaya (*Carica papaya*)[44]	12·9	9	46·0	86·9	...

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Fruits						
Apple, var. Baldwin, dried (*Malus sylvestris*)[5]	...	6·6	2·6	7·5	...	0·0
Apple protein, extracted, var. Baldwin[5] ...	53·1	6·6	2·8	7·0	...	0·0
Banana-'Pachabale' (*Musa cavendishii*)[4] ...	...	6·1	8·3	5·8	8·5	...
Banana-'Kadabale' (*Musa balbisiana*)[4] ...	...	5·1	10·3	6·5	5·3	...
Banana-'Rasabale' (*Musa sapientum*)[4] ...	...	5·3	7·1	6·6	6·3	...
Tubers						
Colocasia (*Colocasia esculenta*)[17] ...	8·5	6.2	1·8	6·2	...	1·4
Potato (*Solanum tuberosum*)[17]	10·2	5·2	1·2	6·7	...	0·7
Potato[27] ...	7·5	5·0	1·5	5·5	...	0·1
Potato[48] ...	...	5·0	2·2	8·3	...	2·1
Potato, whole, var. King Edward[12] ...	...	4·4	1·7	5·0	...	0·8
Potato, peeled[49]† ...	...	0·4	0·1	0·3	...	0·1
Potato globulin (tuberin)[11]	...	5·2	4·1	4·7	...	...
Potato globulin (tuberin)[12]	...	6·0	2·2	7·7	...	1·6
Potato globulin (tuberin)[15]	86·6	4·8	2·2	3·6	...	2·3
Potato globulin (tuberin)[16]...	...	...	...	8·3	...	...
Potato, var. King Edward, N.P.N. fraction[8] ...	...	2·6	1·1	1·9	...	...
Sweet potato (*Ipomeoa batatas*)[26] ...	...	5·9	...	...	5·0	2·1
Sweet potato[27] ...	6·3	5·2	2·4	5·5	...	2·1
Sweet potato[50] ...	...	2·9	1·4	4·3	...	1·8
Sweet potato (local)[17] ...	1·5	3·5	1·5	6·4	...	1·0
Sweet potato (Bombay)[17] ...	3·9	5·2	1·5	5·0	...	0·8
Tapioca (*Manihot esculenta*)[17]	1·3	7·7	1·5	6·2	...	0·5
Tapioca protein[19] ...	...	8·4	...	...	3·3	1·3
Tapioca, N.P.N. fraction[19]	...	1·8	2·7	9·7	2·3	0·7
Yam, elephant (*Amorphophallus campanulatus*)[17] ...	9·3	11·2	1·6	4·4	...	0·6
Vegetables, leafy						
Leafy vegetable[51] ...	...	7·0	2·1	5·7	5·4	1·9
Amaranth leaves (*Amaranthus gangeticus*)[34]	29·7	3·8	2·0	4·0	3·0	1·1
Cabbage (*Brassica oleracea capitata*)[26] ...	...	6·5	...	...	4·6	1·4

† Percentage of amino acids on the basis of dry weight.

OF FRUIT, TUBER AND VEGETABLE PROTEINS

ACIDS							Method of estima- tion*
Phenyl- alanine %	Cystine %	Methio- nine %	Threonine %	Leucine %	Isoleucine %	Valine %	
6·2	...	3·2	5·8	9·8	10·0	7·0	M
6·0	2·1	3·0	5·3	10·4	9·6	6·4	M
2·4	1·7	...	...	...	...	...	CC
3·7	1·4	...	...	...	...	...	CC
4·8	2·3	...	...	...	...	...	CC
5·2	...	1·0	4·7	8·9	5·2	6·0	M
4·1	...	1·0	3·9	5·4	5·3	5·0	M
4·7	...	1·5	3·9	4·8	4·3	5·8	M
5·9	...	2·5	6·9	9·6	3·7	5·3	MM
5·4	1·7	1·6	3·7	...	...	4·8	MM
0·4	...	0·1	0·4	0·6	0·3	0·5	M
...	5·4	...	...	...	...	...	...
6·6	2 1	2·3	5·9	...	...	6·1	MM
5·9	0·9	2·6	6·9	9·6	5·0	7·6	MM
...	...	...	...	...	...	...	M
4·1	1·2	0·8	1·1	...	...	3·3	MM
...	2·5	...	...	...	...	...	C
6·1	...	2 6	5·7	5·6	5 1	9·3	M
4·3	...	1·7	3·8	4·8	3·6	5·6	M
4·1	...	1·0	6 4	6·7	7·5	6·7	M
5·0	...	1·4	5·3	6·8	6 2	9·5	M
3·5	...	0·6	3·8	5·6	5·3	4·5	M
...	1·8	...	...	...	...	...	C
...	2·8	...	...	...	...	...	C
6·2	...	1·0	4·5	5 9	5·0	5·0	M
4·5	2·0	2·3	4·1	...	...	...	MM
2·8	0·7	1·1	2·2	5·9	4·7	4·5	M
...	1·5	...	...	...	...	...	...

* (C: Chemical; CC: Chromatographic; M: Microbiological; MM: Miscellaneous).

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Chakur Manis (*Sauropus androgynus*)[52] ...	26·0	5·8	...	...	5·3	...
Drumstick leaves (*Moringa oleifera*)[31] ...	31·3	6·0	2·1	4·3	...	1·9
Drumstick leaf protein[38] ...	44·1	5·7	2·0	5·0	5·6	2·0
Kankun leaf (*Ipomoea aquatica*)[31] ...	29·4	4·8	1·6	3·8	...	1·5
Sesbania leaves (*Sesbania grandiflora*)[31] ...	35·7	5·8	1·9	4·0	...	1·6
Sesbania leaf protein[38] ...	63·6	5·6	2·2	5·2	5·8	2·0
Spinach (*Spinacia oleracea*)[27]	24·1	6·4	2·8	7·6	...	1·9
Vegetables, non-leafy						
Brinjal (*Solanum melongena*)[31] ...	16·4	3·4	1·7	1·6	...	0·9
Broccoli (*Brassica oleracea botrytis*)[39] ...	29·4	5·8	1·6	5·3	...	1·3
Broccoli heads[27] ...	40·7	6·5	2·1	2·7	...	1·2
Broccoli stalks[27] ...	23·6	5·3	1·8	5·1	...	1·0
Carrot (*Daucus carota*)[39] ...	6·0	3·6	1·5	3·1	...	0·6
Carrot[49] ...	9·1	0·7	0·7	1·1	...	0·2
Cauliflower (*Brassica oleracea botrytis*)[39] ...	24·3	4·9	2·1	5·6	...	1·6
Drumstick bean (*Moringa oleifera*)[31] ...	21·9	3·6	1·1	1·5	...	0·8
Jack seed (*Artocarpus heterophyllus*)[31] ...	10·9	1·9	1·0	4·8	...	1·3
Okra (*Hibiscus esculentus*)[31]	20·4	2·5	1·1	2·5	...	0·7
Plantain, green (*Musa paradisiaca*)[17] ...	2·7	4·1	4·5	5·6	...	0·7
Sweet corn (*Zea mays saccharata*)[39] ...	16·1	4·9	2·6	3·8	...	0·5

ACIDS							
Phenyl-alanine %	Cystine %	Methio-nine %	Threonine %	Leucine %	Isoleucine %	Valine %	Method of Estima-tion
5·0	1·0	1·2	5·9	...	...	3·7	CC
6·4	3·3	2·0	4·9	9·3	6·3	7·1	MM
6·0	1·8	2·0	4·8	...	...	7.2	CC
5·8	2·1	1·7	4·9	8·0	5·7	6·3	MM
6·0	1·5	1·4	4·8	8·9	6·2	6·8	MM
6·0	1·5	1·6	4·8	...	...	7·0	CC
5·4	...	2·0	5·5	8·0	5·4	7·1	M
4·3	...	0·9	3·7	6·3	5·1	5·9	MM
3·3	...	2·4	3·8	6·1	3·6	3·9	M
4·0	...	1·2	3·7	4·8	4·0	5·7	M
3·6	...	1·3	3·8	4·5	3·7	5·6	M
4·1	...	1·0	4·0	5·6	4·4	5·7	M
2·8	...	0·6	2·7	4·8	2·9	3·4	M
3·7	...	2·6	5·0	7·2	4·4	6·4	M
4·3	2·7	1·4	3·9	6·5	4·4	5·4	MM
7·7	1·4	1·4	5·8	8·0	7·2	8·8	MM
3·9	0·8	1·2	3·8	6·2	4·2	5·9	MM
4·5	...	0·6	2·7	5·4	5·1	4·4	M
6·0	...	1·7	4·1	10·8	3·8	6·6	M

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CHAPTER VII

MILK

Cow's milk as a wholesome food and casein as a near perfect protein are widely recognized. Milk occupies a pre-eminent place in the dietary of all age groups and especially in that of infants and children[1]. It is computed that, of the total quantity of liquid milk produced in the world, about 10 per cent is used for feeding young animals and 35 per cent for human consumption; of the balance, about 45 per cent is taken up for butter making and nearly 8 per cent for cheese making[2]. Apart from consumption of milk as such, considerable quantities of milk solids are incorporated in bread and other baked goods with a view to improving their nutritive value, as also their organoleptic quality[3-14].

The production and consumption of milk, however, are not the same in every country[15-18]. In general, the *per capita* production is considerably higher in the economically advanced countries[15, 16] due to factors such as the availability of enough pasture land for promoting dairying without having to draw upon the same land for growing human food[17]. Thus, for these reasons, while in Sweden the net amounts of milk available for consumption by the entire population corresponds to about 5 pounds per head per day[16], the quantities produced in Chile can hardly supply one pound, even if the consumption is restricted exclusively to infants and children[18]. Though India has a larger cattle population than any other country in the world, she has one of the lowest rates for the production of milk and for the consumption of milk and milk products[19]. The present Indian production would correspond to 5.4 oz. per head per day[20] and the consumption is reported to be about 80 per cent of this figure[21]. Various suggestions for increasing the milk output have been advanced from time to time, including a more rational crop planning and diversion of some of the land under cereals to growing concentrates and pasture for the milch-animals[22].

Among well known milk products which contribute, in varying measure, to the protein content of dietaries in different parts of the world, skim milk powder[4, 10, 23, 24], cheese[10, 25-27] and casein[28-32] deserve special mention. Besides, certain indigenous milk preparations are of importance in particular regions. Among these mention may be made of *channa*[*][33-39], *dahi*[†][34-41], *kheer*[‡][34-39] and

* *Channa* is the coagulum formed by adding acid or acidic liquids (citric acid, lemon juice or acid whey) to boiling milk and consists mostly of casein with some occluded milk fat.

† *Dahi* is the curd resultiug from the lactic fermentation of milk allowed to proceed overnight after inoculating lukewarm milk with a culture of home-made curd.

‡ *Kheer* is condensed milk and is prepared by concentrating milk to a third of the original volume over a steady fire.

khoa§ [34-39, 42, 43] which are popular in India and *koumiss** [35, 36, 44], *kefir*† [35, 36] and *shubat*‡ [45, 46] which are popular throughout the Middle East. Whey[10, 47-59], which is a bye-product from the manufacture of cheese[47-50], casein[47, 48] and *channa*[51] and (sweet cream) buttermilk[60-63], which is a bye-product from the manufacture of butter, are also potential sources of dietary proteins.

Milk other than cow's: Buffalo's milk is common in most tropical and sub-tropical countries and is used in the same way as cow's milk[64-66]. Mare's milk is a potential source of food[44] which is well digested and absorbed by infants[67]. Cheese[45] and other products[46] made out of camel's milk are widely consumed in central Asia and are considered to be a cure for anaemia. Ewe's milk is popular in Hungary[68] and Israel[69]. In view of its high nutritive value and digestibility, Germany has considered extended use of ewe's milk as a means of improving the diet of her people[70]. Ass's milk, which is often used for human consumption in Mexico[71], nearly approaches human milk in composition[72].

Protein content: The protein content of cow's milk is 3.0-3.4 per cent[64, 73-77]; cow's colostrum, 13.7-15.0 per cent[75, 77-79]; buffalo's milk, 3.4-4.2 per cent[64, 76, 77, 80, 81]; ewe's milk, 4.7-5.6 per cent[8, 76, 77]; goat's milk, 3.7-3.8 per cent[64, 76, 77]; camel's milk, 3.5-3.8 per cent[45]; mare's milk, 1.9 per cent[67]; ass's milk, 1.4-3.1 per cent[71, 72, 77]; human milk, 1.2-1.5 per cent[53, 73, 77, 82]; fresh whey, 0.8-1.1 per cent[52, 53, 83]; dried whey, whole, 12.3-13.5 per cent[52, 56, 60]; dried whey, fermented, 38.5 per cent[57]; dried (sweet cream) buttermilk, 32.3–35.0 per cent[60, 61]; dried milk, whole, 22.0–25.7 per cent[74, 84, 85]; dried milk, skimmed, 35.5-38.0 per cent[74, 86-91]; cheese, 6.7-21.9 per cent[26]; *channa*, 13.4-20.0 per cent[33, 35, 39]; *dahi*, 2.9-4.2 per cent[35, 39, 41]; *kheer*, 6.9-13.0 per cent[35, 39] and *khoa*, 18.0-29.0 per cent[35, 39, 42].

About 5 per cent of the total nitrogen of cow's milk[92-94] and 20-40 per cent of the total nitrogen of human milk[95] are accounted for by non-protein constituents, chiefly urea.

Amino acid composition: The amino acid composition of the proteins of milk and milk products is presented in Table XIV. Except for a slight deficiency in cystine[73, 85, 96-99], whole milk proteins contain the other essential amino acids in adequate amounts and in balanced proportions[73, 74, 85, 96-98, 100] and are particularly rich[8] in the two amino acids, lysine and valine, in which cereal proteins are generally low. The deficiency of cystine in whole milk proteins has been

§ *Khoa* is evaporated milk and is widely used in confectionary. It is prepared by evaporating milk with rapid stirring over a steady fire to a moisture content of 25-30 per cent.

* *Koumiss* is a mild alcoholic drink prepared by souring mare's milk with yeast.

† *Kefir* is similar to *koumiss*, but is prepared from goat's and ewe's milk.

‡ *Shubat* is similar to *koumiss*, but is prepared from camel's milk.

confirmed by feeding experiments[99] and this deficiency is even greater in casein[73, 96, 98, 101-109]. On the other hand, lactalbumin[73, 96, 98, 102, 103, 109, 110] is particularly rich in this amino acid and to some extent compensates for its deficiency in casein. In addition to lactalbumin[73, 96, 98, 102, 103, 109-112], β-lactoglobulin[96, 98, 100, 113-118], whey proteins[108, 119] and buttermilk proteins[119] are well balanced with respect to all the essential amino acids. β-lactoglobulin is particularly rich in lysine[96, 98, 100, 113, 115, 116, 118].

The proteins of the milk of the buffalo[77, 80, 81, 120], ewe[75, 77], goat[77], sow[121] and ass[77] resemble cow's milk proteins in amino acid composition. Human milk proteins[73, 96, 101, 108, 109, 122] differ from cow's milk proteins mainly in having a higher cystine content. Values reported in the literature for the methionine content of human milk proteins are, however, highly variable[73, 77, 82, 96, 97, 101, 108, 109, 122, 123]. The proteins in cow's[75, 77-79], buffalo's[77] and human[77, 123] colostrum contain more threonine than the proteins in the corresponding mature milks.

Nutritive value: Cow's milk proteins possess a high digestibility[40, 65, 124-129], biological value[40, 65, 124-132] and growth-promoting value[40, 64, 129]. They are, however, inferior in nutritive value to whole egg proteins[125, 131, 133, 134], more so in the nutrition of experimental animals than of human beings[125]. Cow's milk proteins are about equal to human milk proteins in infant nutrition[135, 136]. While the biological value and digestibility of the proteins in buffalo's milk[65] and goat's milk[65] are nearly of the same order as those of the proteins in cow's milk, the growth-promoting value of goat's milk proteins is distinctly lower[64].

The superior nutritive value of whole milk proteins over casein is more evident at low levels of feeding than at higher levels[89]. For maintenance in adult rats[137], casein is slightly superior to groundnut proteins, but inferior to wheat gluten, beef proteins and egg proteins. For promoting growth in young rats[138], casein is of the same order as beef proteins and whole egg proteins, being superior to wheat gluten and groundnut proteins but inferior to egg albumin. For human subjects[139], cooked casein is superior in nutritive value to wheat gluten and groundnut proteins, nearly equal to beef proteins, but distinctly inferior to egg proteins. The superiority of lactalbumin over casein has been established in the case of rats[110, 136, 138, 140, 141] and dogs[102, 142], but has not been confirmed in the case of human beings[136]. Whey proteins, whether heat-coagulated[59], dialyzed[143], or in the form of iron complexes (ferrilactins)[110, 144], possess a high growth-promoting value.

Processing: The biological value and digestibility of raw casein for human subjects are reported to improve on cooking[139]. Both casein[145, 146] and lactalbumin[145, 147] suffer heat injury when subjected to processing at high temperatures.

Simmering of milk in an open pan for 15 minutes[148], but not pasteurization involving heating at 65°C for 30 minutes[149], is reported

to depress the protein quality of milk to a considerable extent. While spray-drying has practically no effect on the nutritive value of skim milk[124] and whey[58, 59] proteins, roller-drying has a deleterious effect. According to a stray unconfirmed report, skim milk acquires the property of producing liver necrosis as a result of the drying process[150]. Protein concentrates prepared by heat coagulation or methanol extraction of spray-dried whey are equal to lactalbumin in nutritive value, but those from roller-dried whey are inferior[59]. There is practically no difference in the nutritive value of the proteins in raw, evaporated or condensed milk[126], in spite of the slight loss of lysine during the process of concentration[74]. While the biological value and digestibility of milk proteins and *kheer* proteins are practically the same, those of *khoa* proteins are significantly lower[129], presumably as a result of the heat-processing, which is also reported to bring about a slight lowering in the arginine and lysine contents[38]. The growth-promoting value of *khoa* proteins is, however, of the same order as that of milk and *kheer* proteins[129].

The effect of fermenting (souring) milk on the nutritive value of its proteins is a subject of controversy[40, 129, 151-153]. Several investigators have not observed any significant difference in the nutritive value of the proteins of fresh and fermented milks, as determined by growth in rats[40, 151, 152] or nitrogen retention in human beings[153]. According to a recent report, however, the biological value of fermented milk (*dahi*) proteins, but not their growth-promoting value, is lower than that of milk proteins[129] and this has been tentatively ascribed to the loss, during the souring process, of certain essential amino acids[129, 154], presumably arginine, lysine and methionine[38].

Supplementary value: The gross supplementary value of milk[155, 156] and milk products[156] like *channa*, *dahi*, *kheer* and *khoa* to the poor rice diet has been amply demonstrated. Milk proteins supplement ragi[88] proteins and rice[157] proteins both by themselves and in combination with legume proteins. As supplement to rice proteins, milk proteins are reported to be superior to legume proteins[158]. Milk proteins also supplement the proteins of different legumes[84], of potato[25], of corn[24, 159-161] and of wheat[7, 8, 24, 89]. It has been reckoned that the most economical use of skim milk powder as a protein supplement to refined wheat flour is at the level of 10 per cent[89].

Whey proteins supplement cereal proteins[57] in general and wheat proteins[162] in particular. Supplementary relationships have also been demonstrated between (sweet cream) buttermilk proteins[24] and corn or wheat proteins and between cheese proteins[25] and wheat proteins.

Milk Products

Dried milk: Consumption of dried milk by infants in preference to fresh milk has been suggested as an effective means of avoiding infection with bovine tuberculosis[163]. The use of skim milk powder

for improving the nutritive value of low cost meals, or indeed any diet is an obvious recommendation[4] and its value in human diets has been repeatedly emphasised[23]. Addition of dried milk to bread and other baked goods[4, 10] increases both their nutritive value[7, 9, 13] and palatability[9, 12, 13]. The baking quality of skim milk powder is reported to be considerably improved by suitable heat treatment[6, 11, 14, 164]. Skim milk can be incorporated in soups[4], beverages[10], cheese spreads[165] and paste goods[166] and can also be used as a medium for growing food yeast[167]. Processed milk powder is reported to be a satisfactory egg substitute[168].

Casein: The manufacture of casein by different processes has been described in detail[169]. The use of casein, either in a modified[32, 170] or hydrolysed[28, 171] form for human consumption is steadily increasing. The method for the preparation of an easily dispersible composite protein food from casein has been patented[32]. Other protein foods of therapeutic value include 'Casinal'[30], 'Casilan'[31] and 'Kralex'[172]. The incorporation of casein in bread leads to small loaf volumes[11] and, in contrast to skim milk powder, the baking quality of casein is not improved by heat treatment[6]. The value of caseinated biscuits in combating protein malnutrition in infants has been recognized[29].

Fermented milk products: Fermented milk (or curds), known as *dahi* in India[34-41] and *yoghurt* in Eastern Europe[154] and the Middle East[27], is a popular article of human diet in these regions, as well as in Scandinavia[173]. In fact, the longevity of Bulgarian peasants has been ascribed to their habit of consuming *yoghurt* in liberal quantities[154]. In certain types of intestinal upset in infants (and even in adults) sour buttermilk is acknowledged as the food of choice, replacing fresh milk in the diet[40, 154]. The preparation of sour buttermilk for use in infant feeding has been described[174]. The value of *yoghurt* in the treatment of protein malnutrition in Egyptian infants has been appreciated[27].

Milk Bye-Products

Buttermilk: Drying, but not condensing nor isolation of casein, has been suggested as the desirable first step in the utilisation of (sweet cream) buttermilk in human diets[61]. It can be incorporated to advantage in ice cream[61, 63] and in baked foods[61, 62]. The baking quality of dried buttermilk is reported to be superior to that of dried skim milk[62].

Whey: Whey, also known as milk serum, is a valuable bye-product obtained in the cheese[48, 175] and casein[48] industries, containing as it does, some of the nutritionally important constituents of milk, namely its soluble proteins and mineral salts[49, 52]. For these reasons, whey has been highly esteemed from early times for its nutritive and therapeutic value[176] and its utilisation as human food in several forms has received considerable attention in recent years[10, 48-50, 52, 54, 177]. However, only a fraction of the several million gallons representing the

annual production of whey in different countries[47] actually finds application at the moment as human food[56, 175]. Much of it still remains to be put into use in this manner. It is reported that nearly 7 billion pounds of whey, containing 70 million pounds of protein, is wasted annually in the United States[175]. In the Indian province of Bengal alone, as much as 1200 tons of whey, resulting from the production of *channa*, is thrown away daily[51].

Since whey closely resembles human milk both in its total protein content and in its albumin to globulin ratio[53], it is ideally suited for use in infant feeding[48, 53, 178], but its high content of mineral salts is a distinct disadvantage[56, 143]. In fact, it has been shown by feeding experiments that the inorganic constituents of whey have a detrimental effect on the nutritive value of whey proteins[143]. The salt content of whey can, however, be reduced to about 0.2 per cent by electrodialysis[56] and the development of this technique is reported to have already reached the pilot plant stage[179]. Desalted whey has practically the same composition[56, 179] and physical properties[179] as human milk and has been used with success as the base for the preparation of infant foods[56, 179].

Since liquid whey can be incorporated as such in many food products[176], the need for its preservation in bulk arises. Different methods of preservation of whey in the liquid state have been worked out, including pasteurisation and addition of formaldehyde or sodium sulphite[180]. However, partial[50, 177] or complete[47, 50, 177] drying of whey and separation of the proteins[50, 175] are desirable pre-requisites for the utilisation of whey solids in human food. Condensed whey can be prepared by vacuum evaporation[48, 181, 182] or spray evaporation[183]. It is reported that the consistency of condensed whey can be controlled independently of the solids content by means of fermentation with propionate-producing micro-organisms[184]. Condensed whey can be solidified by incorporation of wheat flour or soya bean flour to a dry pulverulent paste for use in a variety of ways[185, 186]. The relative advantages of using the spray drier[48, 181, 182, 187, 188], roller drier[182], tunnel drier[48], drum drier[48] or vacuum drier[189] have been discussed. Removal of cations in whey by means of ion-exchange resins prior to processing is reported to have the advantage that condensed whey prepared from it is free from objectionable cooked odours or flavours, while the spray-dried powder prepared from it has superior keeping quality and easy dispersibility in water[190]. The isolation of whey proteins[50, 175, 188, 191-193] and their utilisation as such[50, 175, 194], or after enzymic hydrolysis[191, 192, 195-197] in various food products have received wide attention.

Whey can be incorporated in different baked foods[48] including bread[187, 198, 199], biscuits[50], cakes[200] and doughnuts[200]. Up to 5 per cent of dried whey can be added to bread without marked deterioration in the quality though, at this level, it is reported to impart a cheesy flavour to the bread[3]. Since the poor baking quality of raw whey is due

to the non-dialyzable fraction which is also heat-labile[6], its baking quality can be considerably improved by suitable heat treatment[6, 200, 201]. Whey has been used as the base for the preparation of both non-alcoholic[52, 177, 202-205] and alcoholic[202, 203, 206-208] beverages. 'Milone'[207, 208] is a well known alcoholic whey beverage. Attempts have been made to incorporate whey in ice cream[205], paste goods[166], soups[48, 50, 52, 177], processed cheese[48-50, 209], and cheese spreads[165]. Whey has also been used as medium for the production of food yeast[14, 83, 167, 210-215] and edible fungi[216].

Lactalbumin: The recovery of lactalbumin from whey[217] and its utilisation in different food products[49, 177] have been described in detail.

TABLE XIII

NUTRITIVE VALUE OF MILK PROTEINS

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Nutritive Value: Coefficient of true digestibility %	Nutritive Value: Protein efficiency ratio
Cow's Milk					
Milk, whole[40] ...	...	8	89·0	93·7	1·3
Milk, whole[64] ...	3·3	10	...	...	1·8
		15	...	...	1·6
Milk, whole[65] ...	...	10	76·5	88·3	...
		15	50·6	86·8	...
Milk, whole[124] ...	...	...	90·0	95·6	...
Milk, whole[126] ...	...	...	85·6	94·2	...
Milk, whole[127] ...	...	...	90·5	93·4	...
Milk, whole[128] ...	...	...	74·0*	94·0*	...
Milk, whole[129] ...	...	10	75·6	94·8	...
		11	...	...	2·0
Milk, whole[130] ...	...	5	93·4	...	...
Milk, whole[131] ...	...	...	85·0	...	...
Milk, whole[132] ...	...	10	82·8	89·7	2·0
Milk, whole[218] ...	...	...	43·0*	...	...
Milk, whole[219] ...	...	...	55·0*	...	...
Milk, condensed[126] ...	...	...	84·6	98·8	...
Milk, evaporated[126] ...	...	...	84·1	93·7	...
Milk, evaporated (commercial lot)[127] ...	...	...	89·4	91·8	...
Milk, evaporated (experimental lot)[127] ...	...	...	87·8	90·9	...
Milk, whole, dried[84] ...	22·0-24·0	3	93·0	...	...
Milk, whole, dried[85] ...	25·0	10	...	...	1·9
Milk, whole, dried[145] ...	...	3	89·0	...	...
Milk, whole, dried[161] ...	...	...	...	...	2·0
Milk, whole, dried[220] ...	...	10	...	...	2·3
Milk, skimmed, dried[25] ...	...	8	89·0	90·0	...
Milk, skimmed, dried[86] ...	38·0	10	...	...	1·5
Milk, skimmed, dried[87] ...	38·0	5	89·0	90·0	...
		10	83·0	90·0	...
Milk, skimmed, dried[221] ...	38·0	5	...	...	2·0
Milk, skimmed, dried[89] ...	37·2	9	...	...	2·8
		15	...	...	2·0
Milk, skimmed, dried[90] ...	37·3	10	...	...	2·6
		15	...	...	2·1
		18	...	...	1·8
Milk, skimmed, dried[134] ...	...	8	84·0	95·0	...
Milk, skimmed, dried[222] ...	...	...	...	89·9	3·2
Milk, skimmed, dried[223] ...	...	10	78·5	96·6	...

* determined by human metabolism experiments.

TABLE XIII. *Nutritive Value of Milk Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Milk, skimmed, dried[224] ...	34·5	5 11	... ...	... ...	1·8 2·9
Milk, skimmed, dried[225] ...	34·6	10	...	...	2·8
Milk, skimmed, dried[226] ...	...	8 10 13	... ...	... ...	3·6 3·3 2·9
Milk, skimmed, dried[227] ...	...	8	87·0	92·6	...
Milk, skimmed, dried, air packed and stored at 37°C for 8 days[227] ...	...	8	86·9	90·9	...
Milk, skimmed, dried, air packed and stored at 37°C for 1 month[227] ...	...	8	78·8	89·4	...
Milk, skimmed, dried air packed and stored at 37°C for 3 months[227] ...	...	8	65·9	85·6	...
Milk, skimmed, dried, gas packed and stored at 37°C for 1 month[227] ...	...	8	83·3	89·6	...
Milk, skimmed, dried, gas packed and stored at 37°C for 2 months[227] ...	...	8	67·5	86·0	...
Milk, skimmed, dried, air packed and stored at 28°C for 3 months[227] ...	...	8	71·2	87·8	...
Milk, skimmed, dried, gas packed and stored at 28°C for 3 months[227] ...	...	8	75·7	88·2	...
Milk, skimmed, dried, stored at room temp. for 19 months[228] ...	...	...	88·5	89·8	...
Milk, skimmed, dried, stored at room temp. for 40 months[228] ...	...	...	81·3	87·6	...
Milk, skimmed, dried, stored at room temp. for 54 months[228] ...	...	...	71·1	88·1	...
Channa[129] ...	...	11	67·2	97·0	...
Cheese[25] ...	...	8	76·0	100·0	...
Cheese[229] ...	...	8	72·0	98·0	...
Fermented milk (dahi)[40] ...	...	8	90·4	91·6	1·3
Fermented milk (dahi)[129]	...	8 11	66·4 ...	97·8 ...	... 2·1
Kheer[129] ...	...	10 11	76·1 ...	97·2 ...	... 2·3
Khoa[129] ...	...	10	68·7	89·9	2.3
Whey powder, roller-dried[58] ...	...	...	81·8-83·5	...	...

TABLE XIII. *Nutritive Value of Milk Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Whey powder, roller-dried[59] ...	...	...	81·8-83·5	74·9-81·3	0·0-0·7
Whey powder, spray-dried[58] ...	...	...	90·3-93·9	...	1·7
Whey powder, spray-dried[59] ...	...	...	90·3-93·9	93·1-99·3	1·3-1·6
Casein[89] ...	...	9	...	...	2·3
		15	...	...	2·0
		10	...	...	2·4
Casein[90] ...	89·7	15	...	...	1·7
		18	...	...	1·9
Casein[110] ...	...	10	...	...	3·1
Casein[130] ...	...	5	70·8	...	...
Casein[136] ...	84·1	...	89·0-94·7*	...	2·7
Casein[137] ...	89·2	...	51·0	96·0	...
Casein[138] ...	...	9	...	...	2·6
Casein[139] ...	...	...	68·5*	95·5*	...
Casein[141] ...	...	10	76·6	...	...
		13	60·0	...	...
Casein[145] ...	...	5	...	93·0	...
		...	69·0	97·0	...
Casein[146] ...	84·4	9	...	...	2·1
		11	...	...	2·0
Casein[224] ...	83·8	11	...	...	2·3
Casein[230] ...	...	10	65·0	100·0	...
		7	...	...	0·7
Casein[231] ...	84·0	10	...	...	1·5
		13	...	...	1·7
Casein[232] ...	...	8	78·8	84·4	...
Casein[233] ...	88·8	18	...	...	2·7
Casein[234] ...	...	10	64·5	95·5	2·0
Casein[235] ...	...	...	66·5	98·9	...
Casein from fresh skim milk powder[236] ...	...	10	70·3	...	2·2
		20	...	...	1·3
Casein from stored skim milk powder[236] ...	...	10	64·5	...	1·1 ; 1·9
		20	...	...	1·0 ; 1·2
		...	57·0	93·0	...
Casein, heated at 140°C for 30 mins.[146] ...	88·8	10	...	...	1·7
		13	...	...	1·6
Casein, heated at 120°C for 72 hrs.[145] ...	...	5	...	95·0	...

* determined by human metabolism experiments.

TABLE XIII. *Nutritive Value of Milk Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Casein, roasted at 150°C for 66 hrs.[145] ...	...	5	...	73·0	...
Casein hydrolysate[141] ...	...	10 13	72·3 64·6	... ...	... ...
Lactalbumin[58] ...	...	...	...	...	2·4
Lactalbumin[59] ...	...	...	...	...	1·8-2·1
Lactalbumin[110] ...	...	...	...	...	3·3
Lactalbumin[136] ...	...	...	90·2-93·3*	...	3·5
Lactalbumin[138] ...	...	9	...	...	3·2
Lactalbumin[141] ...	...	10 13	89·8 76·6	... ...	... ...
Lactalbumin[145] ...	...	3 5	92·0 66·0	... 95·0	... ...
Lactalbumin[237] ...	...	...	85·0	97·6	...
Lactalbumin[238] ...	...	9	...	...	2·9
Lactalbumin, heat-coagulated[144] ...	...	...	...	...	3·3–3·7
Lactalbumin, heated at 120°C for 72 hrs.[145] ...	...	5	56·0	69·0	...
Lactalbumin hydrolysate[141]	...	10 13	79·2 70·1	... ...	... ...
Whey protein[144] ...	...	...	...	...	3·6
Whey protein[235] ...	...	...	86·0†	...	...
Whey protein, heat-coagulated[59] ...	...	...	...	...	2·1-2·5
Whey protein iron complex (ferrilactin)[110] ...	...	...	...	...	3·4
Milk from other animals					
Buffalo's milk, whole[64] ...	3.6	10 15	... ...	... ...	2·0 1·4
Buffalo's milk, whole[65] ...	...	10 15	66·7 53·9	82·0 82·4	... ...
Goat's milk, whole[64] ...	3·7	10 15	... ...	... ...	1·0 0·8
Goat's milk, whole[65] ...	...	10 15	67·7 50·4	85·5 85·2	... ...

* determined by human metabolism experiments.
† denotes Net Protein Utilisation (Biological value × Coefficient of true digestibility.)

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Cow's Milk						
Colostrum[75] ...	15·0	4·2	2·4	8·0	...	...
Colostrum[77] ...	16·9	2·8	2·6	7·2	...	2·0
Colostrum (unfertilised feed)[79] ...	14·0	5·2	2·7	7·8	...	1·8
Colostrum (fertilised feed)[79]	13·7	4·6	2·6	7·4	...	1·8
Colostrum, 1 hr. after parturition[78] ...	14·0	5·3	2·8	7·6	...	1·8
Colostrum, 24 hrs. after parturition[78] ...	10·2	5·0	2·9	7·2	...	2·3
Colostrum, 24 hrs. after parturition (unfertilised feed)[79] ...	6·5	5·5	2·8	7·6	...	1·6
Colostrum, 24 hrs. after parturition (fertilised feed)[79] ...	8·1	4·3	2·7	7·7	...	1·7
Milk, whole[73] ...	3·3	3·8	1·9	6·1	5·2	1·4
Milk, whole[74] ...	3·0	3·4	2·3	8·9	5·3	1·4
Milk, whole[75] ...	3·4	3·5	2·7	8·5	...	...
Milk, whole[85] ...	...	4·3	2·5	7·5	5·3	1·6
Milk, whole[96] ...	...	4·3	2·6	7·5	5·3	1·6
Milk, whole[97] ...	...	4·3	2·5	7·5	5·3	1·6
Milk, whole[98] ...	...	4·2	2·6	8·7	6·0	1·5
Milk, whole[100] ...	...	3·6	2·4	8·7	...	1·3
Milk, whole[101] ...	...	4·3	2·5	7·5	5·3	1·6
Milk, whole (Sindhi breed)[77]	3·2	3·9	1·8	11·6	...	1·2
Milk, whole (Cross breed)[239]	...	2·2	1·9	6·1	...	1·2
Milk, 60 days after parturition[78] ...	3·4	3·8	2·8	7·8	...	1·5
Milk, 60 days after parturition (unfertilised feed)[79]	3·2	4·2	2·8	8·0	...	1·4
Milk, 60 days after parturition (fertilised feed)[79] ...	3·3	4·0	2·8	7·8	...	1·6
Milk, 90 days after parturition[78] ...	3·6	4·0	3·2	6·8	...	1·7
Milk, terminal (unfertilised feed)[79] ...	4·6	4·0	2·7	7·9	...	1·4
Milk, terminal (fertilised feed)[79] ...	4·8	4·0	2·9	7·6	...	1·3
Milk, evaporated[74] ...	6·5	3·4	2·0	7·4	4·9	1·2
Milk, evaporated[107] ...	...	4·1	2·8	8·4	5·9	1·5
Milk, evaporated[240] ...	6·9	3·2	2·5	7·2	5·3	1·4
Milk, evaporated, stored for 5 years[240] ...	6·9	2·8	2·1	5·9	5·3	1·3
Milk, whole, dried[74] ...	25·7	3·5	2·4	8·1	5·5	1·4
Milk, whole, spray-dried[97]	...	3·2	2·6	8·2	6·2	1·7
Milk, skimmed, dried[74] ...	35·5	3·1	2·4	8·3	5·3	1·4
Milk, skimmed, dried[91] ...	35·8	3·1	2·3	7·8	5·0	1·4
Milk, skimmed, dried[113] ...	...	...	...	...	...	...
Milk, skimmed, dried[119] ...	40·0	3·0	3·3	7·3	2·3	1·0
Milk, skimmed, dried, stored for 51 months[91] ...	36·0	3·0	2·2	7·0	5·0	1·3

* (C: Chemical; CC: Chromatographic;

ACIDS							Method of estimation*
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
4·5	...	1·9	7·0	9·1	4·7	7·7	M
3·6	...	2·0	9·6	10·1	2·4	7·9	M
4·5	...	1·8	7·4	8·2	5·2	8·3	M
4·6	...	1·8	7·5	8·5	5·4	8·4	M
4·6	...	1·7	6·9	9·7	5·8	8·8	M
4·5	...	1·7	6·0	8·8	6·3	8·3	M
4·6	...	1·9	7·6	8·6	5·9	8·0	M
4·6	...	1·8	7·3	8·5	5·8	8·3	M
5·4	0·8	3·0	4·6	14·8	5·1	5·2	C
4·5	...	1·9	4·6	10·9	6·3	6·3	M
4·8	...	2·7	4·3	9·2	5·9	7·1	M
5·7	1·2	2·8	4·6	16·2	4·4	4·5	MM
5·7	1·0	3·4	4·5	11·3	8·5	8·4	MM
5·7	1·1	2·8	4·6	11·3	6·2	6·6	MM
5·5	1·0	3·2	4·7	11·0	7·5	7·0	MM
5·3	...	2·1	4·0	9·9	5·2	6·6	M
5·7	1·1	2·8	4·6	15·0	4·4	5·0	MM
3·8	...	2·4	5·7	8·9	3·2	6·5	M
2·9	...	2·4	4·4	8·6	3·9	5·7	M
5·3	...	2·4	5·0	10·3	7·0	7·3	M
4·9	...	2·3	4·6	9·3	6·6	7·3	M
4·6	...	2·1	4·7	9·8	6·8	7·4	M
4·5	...	1·8	4·5	10·0	7·1	7·5	M
5·0	...	2·3	5·4	9·1	6·9	7·3	M
4·7	...	2·3	5·4	8·4	6·8	7·7	M
4·2	...	2·2	4·9	11·2	6·2	6·2	M
5·7	0·9	3·6	4·0	10·8	7·2	7·6	MM
4·9	...	1·9	4·6	10·0	7·2	6·4	M
4·9	...	2·0	4·7	9·9	7·2	6·5	M
4·6	...	2·2	4·8	11·8	6·5	6·2	M
6·5	0·8	3·4	4·7	8·7	7·2	7·0	MM
4·5	...	2·1	4·5	10·6	6·0	5·9	M
5·4	...	2·5	4·1	9·8	6·0	6·0	M
...	...	2·2	...	...	...	...	C
5·0	...	2·3	4·3	9·3	7·3	6·0	M
5·3	...	2·3	4·0	9·6	6·1	6·0	M

M: Microbiological; MM: Miscellaneous).

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Cheese[98]	...	3·6	3·3	8·5	6·8	1·6
Cheese (Cheddar)[107]	...	3·5	3·2	8·2	6·9	1·6
Fermented milk (dahi)[38]	...	1·5	1·9	5·7	...	1·2
Fermented milk (buttermilk), dried[119]	38·8	3·1	2·6	6·7	2·8	1·3
Khoa[38]	...	3·1	2·0	5·8	...	1·2
		3·9	2·0	6·0	5·5	1·3
Whey[106]	...	...	...	...	...	...
Whey, dried[119]	16·9	1·8	1·2	4·7	0·6	0·6
Casein[73]	...	3·9	2·0	6·0	5·5	1·3
Casein[74]	...	3·6	2·6	8·3	5·7	1·2
Casein[96]	...	4·2	3·0	7·9	6·9	1·2
Casein[98]	...	4·2	3·2	8·5	6·4	1·3
Casein[100]	...	3·9	2·8	7·7	...	1·1
Casein[101]	...	4·1	2·5	6·9	6·4	1·5
Casein[103]	...	3·7	3·0	7·7	5·4	1·4
Casein[104]	97·7	4·1	3·1	8·2	6·3	1·2
Casein[105]	82·6	3·9	3·4	7·0	5·5	1·4
Casein[106]	...	...	...	...	...	...
Casein[107]	...	3·6	2·9	7·1	6·4	1·3
Casein[108]	...	3·8	1·8	6·2	6·0	1·1
Casein[109]	...	3·7	1·7	6·1	5·8	1·4
Casein[111]	...	3·6	2·6	7·6	6·5	...
Casein[112]	...	...	...	...	...	...
Casein[118]	...	4·0	3·1	7·7	...	1·2
Casein[119]	96·9	4·2	4·2	8·8	5·6	1·0
Casein[241]	85·0	3·8	2·8-3·0	8·1	6·2	1·3
Casein hydrolysate[102]	...	4·3	3·1	7·3	2·8	1·4
Kralex (milk protein supplement)[172]	13·2	3·8	2·9	8·0	6·0	1·2
Lactalbumin[73]	...	3·6	1·4	6·2	3·5	2·1
Lactalbumin[96]	...	3·9	2·1	9·6	4·4	2·5
Lactalbumin[98]	...	4·0	2·3	10·5	5·3	2·5
Lactalbumin[103]	...	3·3	2·1	7·1	3·1	2·2
Lactalbumin[109]	...	4·0	1·8	6·3	3·6	1·9
Lactalbumin[110]	...	4·0	...	10·5	5·3	...
Lactalbumin[111]	...	3·2	1·8	8·4	4·6	...
Lactalbumin[112]	...	...	...	...	...	...
Lactalbumin hydrolysate[102]	92·5	4·1	2·1	9·2	2·7	2·1
β-Lactoglobulin[96]	...	3·0	1·5	11·4	4·3	2·0
β-Lactoglobulin[98]	...	3·0	1·8	11·4	4·3	2·0
β-Lactoglobulin[100]	...	2·8	1·5	11·1	...	2·1
β-Lactoglobulin[113]	97·5	2·9	1·6	11·4	3·8	1·9
β-Lactoglobulin[114]	...	...	1·6	...	...	...
β-Lactoglobulin[115]	...	2·9	1·6	12·6	3·6	...
β-Lactoglobulin[116]	97·5	2·9	1·7	11·2	3·9	...
β-Lactoglobulin[118]	...	3·2	1·6	11·0	...	1·8
Whey protein[103]	...	3·5	1·4	7·9	4·7	1·8
Whey polypeptide iron complex (carniferrin)[110]	...	0·2	...	3·0	0·9	...

ACIDS							
Phenyl-alanine %	Cystine %	Methio-nine %	Threonine %	Leucine %	Isoleucine %	Valine %	Method of Estima-tion
6·4	0·4	3·5	3·7	9·0	7·3	7·7	MM
6·4	0·4	3·5	3·7	9·0	7·1	7·8	MM
3·0	...	1·8	5·9	10·2	3·2	6·2	M
4·1	...	2·1	4·4	9·5	7·5	7·7	M
3·4	...	2·2	4·9	9·9	3·2	6·1	M
5·5	0·4	3·1	4·6	14·4	5·2	5·3	C
...	2·6	3·2	...	...	...	...	C
3·0	...	1·2	4·7	7·1	5·9	4·7	M
5·5	0·4	3·1	4·6	14·4	5·2	5·3	C
5·2	...	2·6	4·2	9·9	6·4	6·2	M
5·6	0·3	3·5	4·1	9·9	6·5	6·7	MM
6·3	0·4	3·5	4·5	10·0	7·5	7·7	MM
5·9	...	2·6	4·2	9·9	5·6	6·7	M
5·2	0·4	3·5	3·9	12·0	5·0	7·0	MM
5·1	0·5	3·1	4·6	10·5	7·1	6·3	M
5·0	0·3	2·8	4·9	9·2	6·1	7·2	C
5·8	0·4	3·4	4·6	9·8	5·8	7·4	MM
...	0·5	2·9	...	...	...	...	C
6·4	0·4	3·5	3·6	9·6	6·9	7·7	MM
...	0·3	3·1	...	...	...	...	C
...	0·4	2·9	...	...	...	...	C
5·3	...	...	4·1	9·5	6·0	7·1	M
...	...	2·6	...	...	...	...	C
6·1	...	2·8	4·3	9·9	6·0	7·3	M
5·3	...	3·2	4·6	11·2	8·3	8·0	M
5·5	...	2·7	4·3	10·3	7·6	7·2	M
5·5	0·4	3·5	3·9	9·1	8·1	7·1	MM
4·9	0·4	2·5	4·8	9·5	6·6	7·0	...
4·5	3·1	2·4	4·3	17·4	4·2	4·0	C
5·4	4·1	2·7	5·4	10·4	6·4	6·4	MM
5·0	4·0	2·6	6·0	12·1	7·5	6·6	MM
3·4	2·5	2·4	4·0	11·3	7·8	4·7	M
...	3·3	2·3	...	...	...	...	C
5·0	4·0	2·6	6·0	...	...	5·6	CC
3·7	...	...	5·6	10·8	6·0	5·9	M
...	...	1·8	...	...	...	...	C
5·1	2·0	2·4	4·3	10·8	7·4	6·3	MM
5·2	3·5	3·6	6·0	15·3	7·0	5·5	MM
4·5	3·5	3·4	6·0	16·1	6·1	6·2	MM
4·3	...	2·5	4·6	15·3	7·0	5·5	M
3·5	3·4	3·2	5·9	15·6	8·4	5·8	MM
3·2	...	2·6	4·8	15·1	7·3	5·5	M
3·8	3·3	...	4·9	15·5	5·9	5·6	CC
3·6	...	3·1	5·2	15·2	7·3	6·2	M
4·6	...	3·2	5·0	16·9	7·3	6·6	M
...	2·5	2·7	...	...	...	...	C
1·4	2·5	3·3	6·1	...	...	5·0	CC

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Milk from other animals						
Ass's milk[77] ...	2·5	3·7	1·4	7·9	...	2·4
Ass's milk casein[242] ...	...	4·3	3·2	7·0	...	...
Ass's milk lactalbumin[242] ...	...	5·1	1·4	9·0	...	...
Buffalo's colostrum[77] ...	20·3	3·8	2·3	6·6	...	1·9
Buffalo's milk[120] ...	...	...	...	7·4	...	1·6
Buffalo's milk (Murrah breed)[77] ...	4·2	3·0	2·3	8·8	...	1·0
Buffalo's milk (Mehsana breed)[80] ...	3·4	3·4	2·0	7·0	...	1·4
Buffalo's milk (Surti breed)[81]	3·7	...	...	7·0	...	1·6
Buffalo's milk (Delhi breed)[81] ...	3·9	...	...	7·6	...	1·8
Buffalo's milk, skimmed, dried[243] ...	...	3·1	2·1	9·1	...	1·2
Buffalo's milk, fermented (dahi)[38] ...	...	1·7	1·7	7·9	...	1·1
Buffalo's milk khoa[38] ...	...	2·3	2·0	8·0	...	1·2
Buffalo's milk casein[120] ...	...	...	...	8·2	...	1·3
Buffalo's milk casein (Surti breed)[81] ...	...	...	...	8·1	...	1·2
Buffalo's milk casein (Delhi breed)[81] ...	...	...	...	8·5	...	1·5
Buffalo's milk whey protein[120] ...	...	...	...	9·5	...	1·1
Buffalo's milk whey protein (Surti breed)[81] ...	...	...	...	9·2	...	1·2
Buffalo's milk whey protein (Delhi breed)[81] ...	...	...	...	9·4	...	1·1
Ewe's colostrum[75] ...	18·3	4·0	2·5	8·0	...	...
Ewe's milk[75] ...	4·7	3·3	2·8	8·6	...	...
Ewe's milk[77] ...	5·6	1·1	2·2	5·4	...	1·4
Goat's milk[77] ...	3·8	5·3	2·1	9·5	...	1·2
Human colostrum[97] ...	...	5·5	2·6	6·5	5·4	2·0
Human colostrum[123] ...	8·6	6·0	2·1	5·9	...	2·4
Human milk (1st day of lactation)[123] ...	4·5	5·8	2·2	5·9	...	2·4
Human milk (2nd day of lactation)[123] ...	2·2	5·3	2·4	6·8	...	1·8
Human milk (4th day of lactation)[123] ...	2·0	3·6	2·0	5·7	...	1·5
Human milk (10th day of lactation)[123] ...	1·8	3·3	2·0	6·1	...	1·4
Human milk[73] ...	1·5	4·5	1·7	6·3	4·9	2·1
Human milk[77] ...	1·3	4·5	1·0	4·3	...	0·9
Human milk[82] ...	1·3	3·5	2·0	5·7	...	1·6
Human milk[96] ...	...	4·3	2·8	7·2	5·2	1·9
Human milk[97] ...	...	5·0	2·7	7·2	5·1	1·9
Human milk[101] ...	...	5·0	2·7	7·2	5·1	1·9
Human milk[122] ...	1·3	...	...	...	...	...
Human milk casein[73] ...	...	3·4	2·0	5·6	5·5	1·5
Human milk casein[108] ...	...	3·3	1·8	5·2	6·1	1·7
Human milk casein[109] ...	...	3·6	1·5	5·5	5·5	1·1
Human milk lactalbumin[73]	...	5·0	1·5	6·6	4·5	2·3

ACIDS							Method of Estimation
Phenyl-alanine %	Cystine %	Methio-nine %	Threonine %	Leucine %	Isoleucine %	Valine %	
2·0	...	3·9	4·9	8·9	3·5	4·6	M
...	...	...	...	...	...	...	C
...	...	...	...	...	...	...	C
3·9	...	1·8	9·0	8·2	2·6	7·7	M
4·8	1·3	2·7	4·8	9·8	5·5	5·7	M
3·9	...	2·9	5·5	10·7	4·4	6·1	M
4·6	1·8	2·8	4·6	9·5	5·7	5·4	M
4·6	...	2·3	5·0	9·7	5·1	5·6	M
4·8	...	2·7	4·7	10·0	5·4	6·0	M
3·4	...	2·9	6·0	10·1	3·4	7·6	M
2·7	...	1·6	4·8	9·6	2·8	6·2	M
2·9	...	2·1	4·1	10·8	3·4	6·7	M
5·5	0·3	2·5	4·6	10·2	7·0	6·9	M
5·7	...	2·3	4·2	10·1	6·4	6·7	M
5·2	...	2·8	4·6	10·5	6·9	7·2	M
5·3	3·8	2·6	3·9	8·7	5·3	4·1	M
5·0	...	3·0	4·0	8·8	5·4	4·2	M
5·3	...	3·0	3·9	8·8	5·3	4·2	M
4·5	...	1·9	6·9	9·7	4·8	8·1	M
4·8	...	2·6	4·4	9·8	5·6	7·5	M
3·9	...	2·7	5·9	10·0	3·1	6·5	M
3·7	...	2·0	6·6	8·4	2·6	4·2	M
5·9	2·5	1·8	5·0	7·9	5·4	6·9	MM
4·4	...	1·0	7·3	7·7	3·5	6·7	M
4·4	...	1·2	7·0	7·7	4·0	6·7	M
4·0	...	1·4	6·0	8·1	4·8	6·4	M
3·4	...	1·2	4·1	8·2	4·9	5·7	M
3·2	...	1·3	4·2	7·5	5·3	5·4	M
5·1	2·7	1·9	4·2	15·2	5·0	4·4	C
2·2	...	0·8	4·2	8·9	3·8	4·7	M
3·3	...	0·9	4·2	7·6	4·8	5·8	M
5·6	3·4	2·2	4·6	9·8	7·5	8·8	MM
5·9	3·4	2·0	4·6	15·0	5·0	5·0	MM
5·9	3·4	2·0	4·6	15·0	5·2	5·5	MM
...	1·9	2·9	...	...	...	...	C
5·8	0·6	2·3	4·5	12·2	6·3	5·0	C
...	0·7	2·2	...	...	...	...	...
...	0·6	2·7	...	...	...	...	C
4·8	3·8	1·7	4·0	16·7	4·3	4·1	C

TABLE XIV. *Amino Acid Composition*

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Human milk lactalbumin[109]	...	5·0	1·7	6·6	4·5	2·5
Human milk whey protein[108]	...	5·2	1·1	5·8	5·2	2·3
Sow's colostrum[121] ...	15·2	6·0	2·1	6·5	...	...
Sow's milk[121] ...	5·7	5·7	2·2	7·4	...	...

ACIDS							
Phenyl-alanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	Method of Estimation
...	4·1	1·4	...	...	...	...	C
...	3·1	1·9	...	...	...	...	C
4·1	...	1·2	5·2	9·1	3·9	6·3	M
3·5	...	1·4	3·5	8·0	4·2	5·0	M

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CHAPTER VIII

MEAT*

IT IS reckoned that approximately one-quarter of the protein requirements of the civilian population in the United States, Canada and England is provided by meat products[1]. The annual *per capita* consumption of meat in these countries is of the order of 140 lbs. in contrast to the very much lower intake in under-developed countries[2]. The consumption of meat in India reported for the year 1931 is only 3 lb. per head per annum[3]. Post-war estimates also place the consumption of meat by the Indian population at very nearly the same figure, distributed almost equally among beef, pork, mutton and goat meat[4].

Protein content: Irrespective of species, mammalian muscle tissue contains about the same amount of proteins—21.2 per cent to 21.9 per cent on the fresh weight basis and 73.7 per cent to 88.1 per cent on the dry weight basis[5]. Beef organs, however, differ widely in their protein content—from 10.6 per cent (brain) to 23.7 per cent (liver) on the fresh weight basis and from 48.4 per cent (brain) to 76.4 per cent (kidney) on the dry weight basis[5]. The protein content of chicken meat is reported to vary from 20.1 per cent to 30.6 per cent on the fresh weight basis and from 75.0 per cent to 92.5 per cent on the dry weight basis[5, 6]. For the same quantity of protein (16.3 g.) supplied by 100 g. of edible portion of beef carcass, one would have to consume 465 g. of fresh whole milk; this gives an idea of the relative concentration of protein in meat as compared to milk[1].

8 per cent to 14 per cent of the total nitrogen in meat is reported to be non-protein in nature[7].

Amino acid composition: The proteins in representative cuts of edible meat such as beef, veal, lamb and pork contain liberal amounts of the essential amino acids in similar proportions[2, 5, 7]. The distribution of the essential amino acids in chicken meat[2, 6] and rabbit muscle[8] also follows approximately the same pattern. In general, meat proteins resemble fish proteins in amino acid composition; so, depending on the availability, fish can replace meat in human diets and *vice versa*, without materially affecting their overall protein value[5]. Compared with egg proteins, meat proteins are higher in histidine and lysine and lower in leucine, isoleucine, valine and methionine[2]. Meat proteins contain larger amounts of arginine, histidine, lysine and methionine and smaller amounts of leucine, isoleucine and valine than milk proteins[2].

As a class, meat proteins are rich sources of lysine[2, 5-12] and methionine[6, 7, 9-12]. While the proteins in horse meat are reported

* Including offal.

to be deficient in tryptophan[9], those in beef are deficient in cystine[13]. The proteins in the beef organs such as brain, liver and kidney are similar in composition and differ from those in muscle tissue in being poorer in lysine[5, 7] and richer in cystine[5, 7], tryptophan[7] and phenylalanine[7]. Human muscle protein[5, 14] is reported to contain the essential amino acids in the following percentages: arginine, 8.8; histidine, 2.4; lysine, 6.6; tyrosine, 4.1; tryptophan, 2.3; phenylalanine, 5.3; cystine, 2.3; leucine, 8.9; and valine, 6.4; this would obviously represent the most optimal proportions of these essential amino acids in human diets conducive to tissue growth and maintenance.

Nutritive value: Meat proteins are almost completely digestible (98 to 100 per cent)[15]. The biological values of the proteins of the meats from both animals and birds have been studied extensively and found to be high (Table XV). Thus, sparrow proteins[16] are reported to possess a biological value as high as 98 per cent. The growth-promoting value of the proteins in chicken and beef compares favourably with that of fish proteins[6]. Beef proteins are inferior in nutritive value to egg albumin or whole egg proteins but superior to casein, wheat gluten or groundnut proteins as judged by growth in young rats[17] and maintenance in young or adult rats[18], as well as human beings[19]. The biological value of beef proteins is higher than that of the proteins of goat meat or buffalo meat[20]. Beef from grass-fed cattle has practically the same nutritive value as that from grain-fed cattle[21].

The performance of growing children on predominantly meat diets has been reported to be superior, in a number of respects, to their performance on diets in which the protein is largely of leguminous origin[22]. Further, the response to gain in weight[23] or regression in anaemic conditions[24] is greater with meat than with milk.

Supplementary value: The supplementary value of meat proteins to pea proteins[25] and egg proteins[26] has been demonstrated. Meat proteins also supplement cereal proteins[27-29] and are superior to groundnut proteins in this respect[29].

Processing: Roasting[21, 30] or corning[21] does not bring about any change in the nutritive value of meat proteins. The essential amino acids in roast beef are completely available to the rat[12], showing thereby that the process of roasting does not exert any deleterious effect. The influence of canning[21, 31] and cooking[32, 33] on the nutritive value of meat proteins is a subject of controversy. Heat-processing, as employed in canning, has no effect on the essential amino acid composition of meat proteins[10, 11]. Cooking does not materially alter their lysine[33] or leucine[34], isoleucine[34] and valine[34] contents. The protein quality of meat is not significantly altered by dehydration[31], especially if it is carried out rapidly at low temperatures[35].

Meat Products: Dehydrated meat, also known as jerky or pemmican, received considerable attention during the second world war but did not become popular because of its poor palatability[36]. Inclusion of a small proportion of connective tissue is reported to enhance the nutritive value of the proteins in dehydrated meat[35]. Beef powder obtained from scrub cattle in Kenya is a cheap edible product with a satisfactory shelf-life and has been used successfully in the treatment of kwashiorkor[37].

Meat Offal

Edible meat bye-products from cattle, sheep and pigs have been surveyed[38]. It has been suggested that among possible supplements to dietary nitrogenous resources, hydrolysates of blood, ossein and horn merit consideration[39].

Blood: The amino acid composition of whole blood proteins are presented in Table XVI. Their value as sources of dietary protein lies in their high lysine content, but they are deficient in isoleucine, and the sulphur-containing amino acids[40, 41]. Likewise, haemoglobin also is deficient in these essential amino acids[42], in contrast to fibrin, which has a fairly well balanced amino acid composition[42, 43]. Fibrin is particularly rich in tryptophan[42], and serum albumin in lysine[43]. The red blood cell stroma proteins as shown with five mammalian species contain practically identical amounts of different essential amino acids; they are richer in histidine but poorer in lysine than the corresponding muscle proteins[5, 44].

The net protein utilization of commercial blood fibrin fed at 10 per cent level in the diet of young growing rats has been found to be fairly high, of the order of 77 per cent[45]. Whole blood proteins, however, do not support normal growth in rats[46, 47]. The supplementary value of blood proteins to wheat gluten and to yeast proteins has been demonstrated[47].

During the second world war, large quantities of blood serum and plasma from the slaughter houses were used for feeding the population of Amsterdam and this helped greatly to reduce the death rate among children and the incidence of hunger oedema in the adult population[48]. The potentialities of dried blood as a source of dietary protein has come to be increasingly realized in Switzerland[49]. Dried beef blood is considered to be a cheap and facile raw material for the production of amino acids, the yield being 0.4 to 0.5 kg. of amino acids, per kg. of dried blood[50]. Specially processed edible blood albumin can be used in baking and for other purposes as a substitute for egg white; a pound of this product is claimed to be equal to the white of 500 eggs[51]. The need for exercising great care in collecting blood from the abattoirs for purposes of being processed as human food has been emphasised[52].

Connective tissue: Of the two major proteins of connective tissue, viz., collagen (or ossein) and elastin, the former gives rise to gelatin on controlled hydrolysis[53]. Collagens from different tissues and from different mammalian sources are similar in amino acid composition, as are elastins from different species of animals and from different tissues[54]. These proteins are deficient in most essential amino acids excepting arginine and lysine in collagen, and phenylalanine, leucine, isoleucine and valine in elastin[54]. Gelatin is a rich source of lysine[41, 54-56] and arginine[40, 41, 43, 54, 56, 57] but is deficient in several essential amino acids[58], notably histidine[40, 41, 43, 54, 56, 57] and the sulphur-containing amino acids[40, 54, 56, 57] and is, in addition, practically devoid of tryptophan[40, 41, 56]. These deficiencies on the one hand, and on the other, the disproportionately high levels of certain non-essential amino acids, notably glycine[59] and proline[59] cause marked amino acid imbalance in gelatin. This is responsible for the inhibition in growth even when gelatin is fed with a mixture of all the essential amino acids[59-61].

Gelatin possesses a fairly high digestibility[62, 63]. The biological value of even 25-30 per cent[62, 64] attributed to it is, in the recently expressed view of Bender *et al.*[65], too high because of the complete absence of tryptophan in this protein. In support of this view, they obtained by the carcass nitrogen method a value of 1-4 per cent for the net protein utilization[65]. Gelatin does not support any growth in rats[56, 59]. Being rich in lysine, gelatin is capable of correcting the deficiency of this amino acid in cereal proteins and therein lies its value in practical nutrition[55]. The supplementary value of gelatin[55, 56, 66], of beef tea[55] (in which gelatin contributes 70 per cent of the nitrogenous extractives) and of a mixture of gelatin and fibrin hydrolysate[56] to wheat proteins has been demonstrated.

Gelatin is a wholesome food[63] and is extensively used as a stabilising agent in the manufacture of ice cream[53, 63] and in other food products, notably gelatin dessert and marshmallow[53].

Keratins (Scleroproteins): Although keratins have been investigated in detail for their amino acid makeup[40, 42, 57, 67-70] (Table XVI) and for their suitability as poultry feed[71-73], there is little possibility, in the foreseeable future, of their being used as a source of protein in human diets. The results on keratins are incorporated here more from the point of view of completeness of information on proteins in general than from the point of view of their potentiality as sources of dietary protein. As a class, they are rich sources of cystine[40, 57, 67-70] and for this reason, it has been suggested that they may be used, after suitable pretreatment, as supplements to vegetable proteins like yeast proteins which are poor in this amino acid[74, 75]. Considerably more than half of the dried and powdered hoofs of cattle, horse or hog has been reported to be digested by proteolytic enzymes, hog hoof being the most digestible and horse hoof, the least; the

undigestible residue, in each case, contains more cystine than the original material[76]. The preparation of keratin hydrolysate in a form suitable for incorporation in bread dough has been patented[77].

Besides being rich in cystine, keratins are also characterised by a high content of arginine[40, 42, 57, 68-70] and threonine[40, 57, 70], and a low content of histidine[40, 57, 67, 68, 70, 78], lysine[57, 67, 68, 70, 78] and methionine[40, 57, 68, 70, 78]. Tryptophan could not be detected in certain keratins[67].

Powdered swine hoofs support growth appreciably in rats and as a source of dietary proteins are reported to be even more satisfactory for growing chicks[71]. On the other hand, growth in rats or chicks is poor on diets based on powdered hog hair[73]. Rats fed diets containing wool[78] or chicken feathers[79] as the sole source of protein do not at all grow unless the diets are supplemented with lysine, histidine, tryptophan and methionine. The effect of particle size and method of grinding the keratins on their nutritive value for rats has been investigated; the rates of growth, in general, show a positive correlation with the degree of subdivision of the keratin[73].

TABLE XV

NUTRITIVE VALUE OF MEAT PROTEINS

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Meat					
Avian					
Chicken, raw[81] ...	...	8	...	...	3·3
Chicken meat, dried[6] ...	75·5	8	...	...	3·6
Crow, whole[16] ...	...	9	68·0	...	...
Pigeon, whole[16] ...	...	9	88·0	...	...
Sparrow, whole[16] ...	...	9	98·0	...	...
Mammalian					
Beef[25] ...	...	10	...	...	2·2
Beef[27] ...	...	...	69·0	...	...
Beef muscle[80] ...	...	...	71·5†	...	...
Beef, raw[32] ...	...	7	67·0	97·6	2·6
Beef, raw[81] ...	...	8	...	...	3·0
Beef, raw[82] ...	...	10	...	...	2·6
		15	...	...	1·7
Beef, loin raw[17] ...	20·5	9	...	...	3·9
Beef round[29] ...	...	9	75·8	100·0	...
Beef round[30] ...	...	10	73·8	99·6	...
Beef round[83] ...	...	9	74·6	100·0	...
Beef round[84] ...	...	10	78·1	99·6	...
Beef round[85] ...	...	10	75·6	99·5	...
Beef round, raw[17] ...	22·8	9	...	...	3·8
Beef round, raw, from grain-fed steers[21] ...	...	10	77·5	99·0	...
Beef round, raw from grass-fed steers[21] ...	...	10	79·2	97·7	...
Beef rib, raw, from grass-fed steers[21] ...	...	10	78·0	98·0	...
Beef steak[86] ...	...	...	84·0*	97·0*	...
Beef, dried[6] ...	90·0	8	...	...	3·3
Beef, dried[20] ...	81·4	10	68·6	97·3	...
		15	53·7	93·4	...
Beef, dehydrated[87] ...	...	8	...	...	2·3
		10	...	...	2·6
		18	...	...	1·8
		20	...	...	2·0
Beef, dehydrated (average of 18 samples)[88] ...	...	10	...	97·1	3·2
Beef powder, laboratory sample, dried, defatted (alcohol—or hexane-extracted)[17] ...	88·4	9	...	...	3·2

† denotes Net Protein Utilisation (Biological value × Coefficient of true digestibility.)
* determined by human metabolism experiments.

TABLE XV. *Nutritive Value of Meat Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Nutritive Value: Coefficient of true digestibility %	Nutritive Value: Protein efficiency ratio
Beef powder, commercial, dried, defatted (benzol-extracted)[17] ...	93·8	9	...	...	2·6
Beef powder, commercial, dried, defatted (benzol-extracted)[18] ...	98·3	2–5	69·4	99·0	...
Beef powder, commercial, dried, defatted (benzol-extracted)[19] ...	98·3	3–5	67·0*	97·0*	...
Beef, boiled to an internal temp. of 84°C[32] ...	...	7	60·0	98·6	2·4
Beef, autoclaved at 15 lb. pr. for 7 mins.[32] ...	...	7	62·0	99·4	2·4
Beef, autoclaved at 15 lb. for 60 mins.[32] ...	...	7	56·0	98·4	1·8
Beef round from grass-fed steers, canned[21] ...	...	10	74·0	94·0	...
Beef round from grain-fed steers, corned[21] ...	...	10	74·5	99·0	...
Beef rib from grass-fed steers, roasted[21] ...	...	10	79·0	98·5	...
Beef round, roasted[30] ...	...	10	74·8	99·3	...
Buffalo meat, dried[20] ...	81·0	10	59·5	94·7	...
		15	46·4	97·1	...
Goat meat, dried[20] ...	71·1	10	60·4	95·2	...
		15	46·7	94·2	...
Ham, whole[91] ...	...	8	74·0	100·0	...
Ham, fresh[26] ...	...	10	...	...	3·3
Ham, cured[26] ...	...	10	...	...	3·2
Ham, dry-cured[26] ...	...	10	...	...	3·3
Horse meat, raw[32] ...	...	5	...	...	3·0
		7	...	...	2·7
Horse meat, autoclaved at 15 lb. pr. for 60 mins.[32]	...	5	...	...	2·5
		7	...	...	2·8
Lamb[25] ...	...	10	...	...	2·3
Mutton, dehydrated (average of 4 samples)[88]	...	10	...	...	3·2
Pork[25] ...	...	10	...	...	2·2
Pork muscle[82] ...	...	10	...	...	2·5
		15	...	...	1·9
Pork tenderloin[28] ...	...	10	...	...	3·3
Pork tenderloin[63] ...	...	10	79·0	100·0	...
Pork, dehydrated[87] ...	...	8	...	...	2·8
		11	...	...	2·4
		17	...	...	1·9
		20	...	...	2·0

* determined by human metabolism experiments.

TABLE XV. *Nutritive Value of Meat Proteins*

SOURCE	Protein content: N × 6.25 %	Level of feeding %	Nutritive Value		
			Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Pork, dehydrated (average of 16 samples)[88] ...	...	10	...	98·2	3·4
Pork, raw, cured[87] ...	...	10	...	...	2·7
		20	...	...	1·9
		29	...	...	1·4
Pork, canned, cured[87] ...	...	9	...	...	2·3
		10	...	...	2·7
		18	...	...	1·8
		20	...	...	1·9
		29	...	...	1·4
Pork, fresh, roasted[87] ...	...	5	...	...	2·3
		18	...	...	1·9
Pork, fresh, fried[87] ...	...	9	...	...	2·6
		17	...	...	1·9
Veal[27] ...	...	...	62·0	...	...
Heart (beef)[80] ...	...	...	66·6†	...	...
Heart (beef)[82] ...	...	10	...	...	3·1
Heart (beef)[89] ...	...	10	74·0	100·0	...
Kidney (beef)[82] ...	...	10	...	...	2·9
Kidney (beef)[89] ...	...	10	77·0	99·0	...
Liver (beef)[80] ...	...	...	65·0†	...	...
Liver (beef)[82] ...	...	10	...	...	2·7
Liver (beef)[89] ...	...	10	77·0	98·0	...
Liver (beef), dried[90] ...	...	5	57·0	88·0	...
Liver (beef), heated at 100°C for 2 weeks[90] ...	...	5	51·0	79·0	...
Liver (beef), extracted with alcohol for 130 hrs.[90]	...	5	25.0	34·0	...
Pancreas residues[80] ...	...	...	38·5†	...	...
Stomach (hog)[80] ...	...	...	57·3†	...	...
Meat Offal					
Blood					
Blood (beef)[80] ...	...	...	3·8†	...	...
Blood fibrin[45] ...	...	10	76·6	...	...
Connective tissue					
Gelatin[62] ...	...	10	25·0	96·0	...
Gelatin[65] ...	...	...	1·4†	...	...

† denotes Net Protein Utilization (Biological value × Coefficient of true digestibility.)

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Meat						
Meat[40] ...	...	7·1	2·2	8·1	3·1	1·2
Meat scraps[92] ...	...	7·0	3·5	5·6	3·2	0·7
Meat scraps[93] ...	...	5·4	3·5	6·1	2·2	0·6
Amphibian						
Amphibian muscle[5] ...	...	6·6	2·1	7·9	4·8	1·4
Frog muscle (leg)[5, 7] ...	17·5	6·6	2·1	8·0	4·7	1·4
Avian						
Avian muscle[5] ...	...	7·0	2·3	8·4	4·1	1·2
Chicken muscle[94] ...	...	7·1	2·3	8·4	4·3	1·2
Chicken muscle (light meat)[5, 7] ...	30·6	6·9	2·3	8·4	4·2	1·3
Chicken muscle (dark meat)[5, 7] ...	26·2	7·1	2·3	8·4	4·3	1·2
Chicken meat, light[6] ...	23·3	5·9	3·7	7·5	...	1·2
Chicken meat, dark[6] ...	18·4	6·1	2·9	8·8	...	0·9
Chicken gizzard[6] ...	19·8	5·6	2·5	6·0	...	0·8
Chicken liver[6] ...	18·9	7·1	3·8	7·3	...	0·7
Mammalian						
Mammal-entire animal[92] ...	...	7·3	2·8	6·5	3·2	1·0
Mammalian muscle[5] ...	...	7·1	2·3	8·7	4·6	1·3
Mammalian muscle[42] ...	...	7·1	2·2	8·1	3·1	1·2
Mammalian muscle[92] ...	...	7·7	3·3	10·0	4·0	1·4
Beef[11] ...	21·4	6·1	3·6	8·7	...	1·0
Beef muscle[94] ...	...	7·7	2·9	8·1	3·4	1·3
Beef muscle[95] ...	...	7·0	2·5	8·2	...	1·3
Beef muscle[96] ...	...	6·0-7·1	2·2-3·5	7·8-8·1	...	1·2-1·3
Beef muscle (Shank)[5, 7] ...	21·9	6·9	2·3	8·1	4·3	1·4
Beef round, lean, raw[9] ...	...	10·1	4·4	8·2	...	1·5
Beef, roasted[12] ...	72·3	6·5	3·3	10·0	...	1·3
Beef muscle protein[43] ...	100·0	6·0	3·5	7·9	4·1	...
Ham, whole, cured[11] ...	15·9	6·4	3·5	8·9	...	1·0
Ham, spiced[10] ...	13·8	6·0	3·0	8·5	...	0·8
Ham, spiced[11] ...	14·6	6·2	3·1	8·1	...	0·9
Horse meat, raw[94] ...	...	6·3	3·6	8·7	3·9	1·5
Horse meat (tough, stringy)[9]	...	8·7	4·2	7·6	...	0·6
Human muscle (leg)[14] ...	...	8·8	2·4	6·6	4·1	2·3
Lamb muscle (leg)[5, 7] ...	21·2	7·6	2·4	8·7	4·9	1·4
Pork muscle[95] ...	...	6·5	3·0	8·7	...	1·3
Pork muscle (chops)[5, 7] ...	21·9	6·6	2·2	8·7	4·4	1·3

* (C: Chemical; M: Microbiological;

ACIDS							Method of Estima- tion*
Phenyl- alanine %	Cystine %	Methio- nine %	Threonine %	Leucine %	Isoleucine %	Valine %	
4–5	1·1	3·3	4·3	12·0	3·4	3–4	MM
5·1	1·2	2·0	3·9	8·0	3·4	6·1	MM
5·1	...	1·1	3·5	8·0	3·4	6·1	M
4·5	1·2	3·2	4·9	...	...	...	C
4·7	1·1	3·2	4·9	...	...	...	C
4·3	1·2	3·4	4·5	...	...	...	C
4·6	1·3	3·2	4·7	...	...	...	MM
3·9	1·0	3·3	4·7	...	...	...	C
4·6	1·1	3·3	4·6	...	...	...	C
3·8	...	2·1	3·9	7·0	5·3	4·7	M
4·0	...	2·8	3·8	7·2	5·7	4·6	M
3·2	...	2·6	4·5	6·0	4·4	3·8	M
4·6	...	4·1	5·1	8·2	5·6	5·6	M
4·5	1·5	3·0	4·5	10·8	...	...	MM
4·5	1·2	3·2	4·9	...	...	...	C
4·5	1·1	3·3	5·2	12·1	3·4	3·4	MM
5·0	1·2	3·2	5·0	8·0	6·0	5·5	MM
3·8	...	2·7	4·5	7·8	5·0	5·2	M
4·9	1·3	3·3	4·6	7·7	6·3	5·8	MM
4·2	...	3·3	4·6	7·9	5·5	5·2	M
3·9-4·8	...	3·0-3·3	4·4-5·4	7·7-12·1	3·4-5·3	3·4-5·2	M
4·9	1·1	3·1	4·6	...	...	...	C
3·6	...	4·1	5·1	7·7	5·7	5·2	MM
4·3	...	3·1	4·9	8·8	4·4	6·0	M
3·9	...	...	5·4	7·7	5·3	5·2	M
3·8	...	2·5	4·2	7·9	4·9	5·4	M
3·9	...	2·4	3·2	7·7	4·8	5·1	M
3·8	...	2·4	4·3	7·7	4·6	4·9	M
5·9	1·0	3·2	4·4	8·0	6·3	5·8	MM
3·6	...	6·2	4·4	7·8	5·1	5·3	MM
5·3	2·3	...	...	8·9	...	6·4	...
4·5	1·2	3·2	5·3	...	...	...	C
4·0	...	2·9	4·6	8·0	5·5	5·4	M
4·0	1·1	3·3	4·6	...	...	...	C

MM: Miscellaneous).

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Trypto-phan %
Rabbit muscle (hind limb)[8]	...	6·9	1·1	9·6	2·1	1·8
Veal muscle (steak)[5, 7] ...	21·2	7·5	2·4	9·6	4·9	1·4
Brain[42] ...	...	6·6	2·6	6·2	4·1	1·3
Brain[92] ...	...	7·4	3·2	7·0	4·1	1·3
Brain[94] ...	...	6·6	2·8	6·5	4·1	1·6
Brain (beef)[5, 7] ...	10·6	6·4	2·5	6·0	5·1	1·6
Brain (beef) dried[97] ...	86·9	5·0	2·2	4·0	3·8	1·3
Brain (human) dried[97] ...	83·8	5·0	2·3	4·4	3·7	1·3
Brain (sheep) dried[97] ...	78·1	5·0	2·3	4·1	3·6	1·1
Heart (beef)[5, 7] ...	17·5	7·4	2·1	7·1	4·4	1·4
Heart muscle (beef)[94] ...	...	7·4	2·7	7·4	4·4	1·4
Kidney[94] ...	...	6·3	2·7	5·5	4·8	1·7
Kidney (beef)[5, 7] ...	21·2	6·9	2·3	6·2	4·6	1·9
Liver[92] ...	...	6·6	2·5	7·0	3·9	1·5
Liver[94] ...	...	6·6	3·1	6·7	4·6	1·4
Liver meal[93] ...	...	4·9	2·2	6·0	2·2	0·6
Liver powder[93] ...	...	2·7	1·8	6·7	1·0	0·3
Liver (beef)[5, 7] ...	23·7	6·6	2·0	6·0	4·6	1·8
Liver (beef)[41] ...	81·1	3·4	1·9	6·1	...	1·4
Lung (beef)[5, 7] ...	16·7	6·3	1·9	5·8	3·8	1·1
Pancreas protein (pork)[43] ...	96·3	6·6	1·4	6·5	4·2	...
Stomach (beef)[5, 7] ...	15·6	6·6	1·7	5·8	3·7	1·0
Reptilian						
Reptilian muscle[5] ...	...	6·8	2·2	7·7	4·8	1·3
Giant African snail, dehydrated, lot[1 98] ...	69·9	9·2	1·4	8·5	...	...
Gaint African snail, dehydrated, lot[2 98] ...	64·9	13·3	1·6	10·0	...	...
Giant African snail, dehydrated, lot[3 98] ...	61·6	6·6	1·6	5·6	...	0·6
Turtle muscle[5, 7] ...	25·0	6·7	2·3	7·7	4·6	1·4
Meat Offal						
Blood						
Blood whole (beef)[40] ...	...	4·2	5·9	8·0	3·8	1·5
Blood meal[41] ...	93·5	4·2	5·6	8·8	...	1·3
Blood meal[92] ...	...	4·2	5·6	8·8	2·2	1·3
Fibrin[42] ...	...	6·8	2·3	7·5	5·1	3·7
Fibrin[92, 94] ...	...	7·8	2·7–2·9	8·8–9.1	5·8–6·0	3·4–3·9
Fibrin (beef)[43] ...	...	7·2	2·2	8·5	6·0	...
Haemoglobin[42] ...	...	3·5	7·6	8·0	3·0	1–2
Haemoglobin[92] ...	...	3·9	8·0	9·1	2·9	1·1
Serum proteins[42] ...	...	5·8	2·6	8·0	5·4	1·7

ACIDS							
Phenyl-alanine %	Cystine %	Methio-nine %	Threonine %	Leucine %	Isoleucine %	Valine %	Method of Estima-tion
1.8	...	...	...	12.0	...	4.9	...
4.4	1.2	3.5	5.1	...	...	...	C
4.9	1.8	...	5.8	13.4	3.6	4.9	MM
5.2	2.0	3.0	5.8	7.4	5.1	4.8	MM
5.8	1.8	3.0	5.8	7.4	5.1	4.8	MM
5.8	1.9	2.9	5.3	...	...	...	C
...	1.4	...	...	...	...	...	C
...	1.5	...	...	...	...	...	C
...	1.2	...	...	...	...	...	C
5.1	1.2	3.2	4.7	...	...	...	C
5.1	1.2	3.2	4.7	8.4	5.2	6.3	MM
5.5	1.5	2.7	4.6	8.0	5.6	5.3	MM
5.5	1.8	2.8	4.6	...	...	...	C
6.1	1.4	3.2	5.3	8.4	4.8	6.0	MM
6.1	1.4	3.2	4.8	8.4	5.6	6.2	MM
4.8	...	1.5	3.2	8.3	4.6	5.2	M
1.1	...	0.6	2.4	2.9	2.1	1.9	M
6.1	1.5	2.9	4.8	...	...	...	C
5.3	...	2.0	3.8	8.3	4.0	5.7	M
4.1	1.5	2.5	3.8	...	...	...	C
3.8	...	...	5.6	7.0	5.9	5.3	M
3.3	1.1	2.8	3.8	...	...	...	C
4.3	1.2	4.0	4.9	...	...	...	C
3.7	...	1.0	...	4.9	4.5	4.3	M
3.4	...	1.3	...	5.8	5.6	4.9	M
3.9	...	1.2	4.3	7.5	4.6	5.2	M
4.3	1.0	3.6	4.9	...	...	...	C
6.2	1.8	1.5	6.6	15–20	2.0	5–6	MM
7.3	...	1.1	4.1	12.2	1.1	7.7	M
7.3	1.8	1.1	4.1	11.9	1.1	7.8	MM
5.9	1.9	2.6	7.9	14.3	5.0	3.9	MM
5.0–6.0	1.9	2.6–3.1	7.3–7.9	7.1–14.0	5.0–5.6	5.6–6.0	MM
4.4	...	...	6.4	6.9	5.9	5.5	M
6.7	0.5	1.4	6.8	16.6	1.5	8.2	MM
7–8	0.5–1.1	1–3	5–6	14.4	0–2	9.0	MM
5.4	3.6	2.1	6.3	18.0	3.0	6.0	MM

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Serum proteins[92] ...	...	5·8	3·3	10·0	5·5	1·9
Serum proteins (beef)[43] ...	93·1	5·3	1·8	7·3	4·9	...
Serum albumin[94] ...	...	6·0	3·5	10·4	5·3	0·3
Serum albumin (bovine)[43] ...	100·0	6·1	4·1	12·3	5·2	...
Serum globulin[94] ...	...	4·8	2·5	6·7	6·8	2·9
Stroma proteins (beef)[44] ...	86·3	6·0	2·4	4·0	3·3	1·4
Stroma proteins (hog)[44] ...	81·9	5·7	2·7	4·3	3·3	1·5
Stroma proteins (horse)[44] ...	80·6	5·8	2·5	4·5	3·3	1·3
Stroma proteins (human)[44]	81·3	5·9	2·6	4·8	3·5	1·4
Stroma proteins (sheep)[44] ...	87·5	5·7	2·8	3·8	2·9	1·2
Connective tissue						
Collagen[92] ...	...	7·6	0·7	4·0	1·1	0·0
Collagen (Gelatin)[94] ...	...	8·7	0·9	5·8	0·7	0·0
Collagen from bovine achilles-tendon[57] ...	100·0	8·0	0·9	3·5	0·9	...
Collagen from mammalian bone, hides or tendons (average of 10 values)[54] ...	100·0	8·8	0·6	5·4	1·0	∠0·01
Collagen from turtle subcutaneous membrane[54]	...	9·0	0·7	5·1	1·0	...
Gelatin[40] ...	...	7·6	1·0	4·3	0·2	0·0
Gelatin[92] ...	...	8·2	0·9	5·0	0·5	0·0
Gelatin (Knox)[41] ...	...	9·1	0·6	5·8	...	0·0
Gelatin (Difco Bacto)[54] ...	100·0	8·3	0·9	5·2	0·9	...
Gelatin from calf skin (Eastman)[54] ...	100·0	6·4	0·6	5·2	0·1	...
Gelatin from pig skin (Eastman)[54] ...	100·0	8·8	0·7	5·1	0·7	...
Gelatin from pig skin[57] ...	100·0	8·0	0·8	4·1	0·4	...
Gelatin (pork skin type)[43] ...	100·0	8·0	0·8	4·1	0·4	...
Elastin[92] ...	...	1·1	0·04	0·5	1·5	0·0
Elastin from tendon[94] ...	...	1·0	0·0	...	1·5	0·0
Elastin (bovine)[57] ...	100·0	1·1	0·1	0·5	1·4	...
Elastin (bovine yellow tendon)[57] ...	96·9	3·1	0·3	1·3	1·7	...
Elastin from mammalian tissues (average of 6 samples)[54] ...	100·0	0·9	0·1	0·4	2·1	∠0·01
Elastin from the ligamentum nuchae (ox)[99]	100·0	1·0	0·0	0·0	1·6	0·0
Tankage[40] ...	67·2	5·9	2·4	7·2	...	0·8
Tankage[92] ...	...	5·8	2·7	6·0	2·7	0·7
Tankage[93] ...	...	6·1	2·7	5·0	2·1	0·7
Keratins						
Keratins[94] ...	...	10·7	1·0	3·2	5·1	1·4
Feathers[92] ...	...	8·0	0·6	1·8	2·3	0·7
Feathers (chicken)[57] ...	93·8	7·5	0·4	1·3	2·2	...
Gorgonin from *Gorgonia flabellum*[67] ...	88·1	4·5	0·9	3·3	13·0	0·0

ACIDS							Method of Estimation
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
5·2	3·5	2·0	6·3	10·1	3·4	7·5	MM
4·7	...	...	5·9	9·4	3·2	7·0	M
7·9	6·5	1·3	5·1	11·9	2·0	7·0	MM
6·4	...	...	6·3	11·3	3·3	5·4	M
...	3·1	1·1	...	8·1	3·3	10·1	MM
...	1·0	2·0	...	...	...	...	C
...	1·4	2·6	...	...	...	...	C
...	1·1	2·7	...	...	...	...	C
...	1·1	2·4	...	...	...	...	C
...	1·1	2·7	...	...	...	...	C
3·6	...	0·7	2·0	3·6	1·9	2·9	MM
2·1	0·1	0·8	2·0	3·1	1·7	2·8	MM
2·5	0·3	0·9	2·5	3·5	1·9	2·9	MM
2·5	0·1	0·9	2·3	3·3	1·9	2·8	M
...	0·1	0·7	3·4	3·5	1·8	2·3	M
1·8	0·1	0·8	1·5	4·0	1·0	2·0	MM
2·3	0·1	0·8	1·9	3·5	1·7	2·8	MM
2·3	...	0·6	2·0	3·5	1·7	2·7	M
2·3	0·1	0·9	2·0	3·1	1·5	2·8	M
1·9	0·1	0·9	2·2	3·1	1·9	2·6	M
2·1	0·1	0·8	2·2	3·2	1·5	2·7	M
2·2	0·1	1·0	1·9	3·2	1·4	2·5	MM
2·2	...	...	1·9	3·2	1·4	2·5	M
4·6	0·6	0·4	2·0	7·0	3·3	13·1	MM
3·1	0·2	0·4	2·5	...	...	...	MM
4·8	0·6	0·1	1·1	7·3	3·4	13·8	MM
4·3	0·7	0·3	1·5	7·6	4·3	13·6	MM
5·3	0·2	0·03	1·2	8·4	3·7	17·3	M
3·3	0·2	0·4	...	...	...	13·5	C
4·2	...	1·3	3·0	7·7	2·7	5·4	M
5·0	0·9	2·0	3·5	8·6	3–4	5·5	MM
4·4	...	0·9	4·0	9·0	4·0	5·7	M
3·7	10–17	1·0	7·2	10·0	5·0	6·0	MM
5·5	8·7	0·5	4·6	8·5	6·4	8·9	MM
5·2	8·2	0·5	4·4	8·0	6·0	8·3	MM
5·7	9·0	...	...	...	...	...	C

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Gorgonin from *Phlexaurella dichotoma*[67] ...	85·6	4·9	0·1	2·8	13·5	0·0
Hair[40] ...	...	8·9	1·0	2·6	3·1	1·3
Hair[92] ...	...	10·0	1·0	3·0	3·3	1·2
Hair (hog)[57] ...	100·0	10·9	1·1	3·8	3·5	...
Hair (human)[68] ...	...	8·9–10·7	0·6	2·4	2·1	...
Hair (human)[70] ...	100·0	8·9	1·2	1·9	2·2	1·0
Hoof[42] ...	...	10·4	1·0	3·2	5·0	1·5
Hoof (cattle)[76] ...	100·0	...	...	...	...	...
Hoof (hog)[76] ...	97·5	...	...	...	...	...
Hoof (horse)[76] ...	100·0	...	...	...	...	...
Horn[92] ...	...	10·4	1·1	3·7	5·3	1·4
Horn (cattle)[57] ...	97·5	10·7	1·0	3·6	5·6	...
Schutes (turtle)[67] ...	88·1	4·2	1·8	1·8	13·1	2·3
Skin[92] ...	...	10·0	0·7	4·5	5·0	1·8
Spongin from *Poifera*[67] ...	81·3	4·3	0·2	3·0	0·8	0·0
Wool[69] ...	100·0	9·9	...	...	5·4	...
Wool[92] ...	...	10·1	1·0	3·1	5·5	1·5
Wool (sheep)[57] ...	100·0	10·6	1·1	3·3	5·6	...

ACIDS							
Phenyl-alanine %	Cystine %	Methio-nine %	Threonine %	Leucine %	Isoleucine %	Valine %	Method of Estima-tion
6·5	7·6	...	...	...	...	...	C
2·7	15·9	Trace	6·4	7–10	3–4	3–6	MM
3·0	10–15	1·0	7·7	8·0	4·5	5·7	MM
2·7	14·4	0·5	6·3	8·3	4·7	5·9	MM
...	13·7	1·0	...	...	...	...	C
2·4	18·0	0·7	8·5	6·4	4·8	5·5	MM
4·0	7·3	...	5·6	15·0	4–5	5·0	MM
...	5·9	...	...	...	...	...	C
...	4·4	...	...	...	...	...	C
...	5·9	...	...	...	...	...	C
4·0	12·4	1–2	5·7	8·0	4·8	5·5	MM
3·2	12·1	0·5	6·1	8·3	4·3	5·5	MM
5·2	8·6	...	...	...	...	...	C
...	3·5	2·6	...	8·3	6–8	5·6	MM
3·3	2·8	...	...	...	...	...	C
3·5	11·0	...	...	10·1	...	4·8	MM
4·0	13·6	0·7	6·5	8·2	4·2	5·4	MM
4·0	13·7	0·6	6·7	8·1	4·5	5·7	MM

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CHAPTER IX

EGGS

Hen's Egg

The early investigations of Osborne and Mendel[1,2] gave the first insight into the high nutritive value of the proteins in whole hen's egg. These proteins contain an amino acid mixture that is very highly digestible and almost perfectly utilisable in adolescent rodent metabolism[3], being superior to milk[4-8] and meat[4,6-10] proteins in this respect. The obvious conclusion is that the essential amino acids in whole egg proteins are present in the proportions optimum for tissue growth and maintenance. It is for this reason that egg proteins have come to form the basic standard against which the relative deficiency of the limiting essential amino acids in different food proteins has been determined and their 'chemical scores' have been calculated[3,11]. Egg proteins have also been widely used in the determination of the biological value of proteins, both as a reference standard[12-14] and for determining the metabolic nitrogen excretions[15].

Protein content: On an average, hen's egg contains 12 per cent protein on the fresh weight basis and 35 per cent protein on the dry weight basis[16]. In protein content, an average sized egg is equivalent to half a pint of milk[17]. Of the total proteins in hen's egg, 65 per cent is contributed by egg white and 35 per cent by egg yolk[18]. Egg white contains five proteins; ovalbumin, 75 per cent; ovomucoid, 13 per cent; ovomucin, 7 per cent; ovoconalbumin, 3 per cent and ovoglobulin, 2 per cent[16]. The two egg yolk proteins, ovovitellin and ovolivetin, are present approximately in the ratio of 4:1[16].

Amino acid composition: The amino acid composition of the proteins of whole egg[19-23], egg white[23,24], egg yolk[23] and of some of the constituent proteins, especially ovalbumin[25-27], has been determined. Whole egg proteins are very well balanced with respect to all the essential amino acids and are particularly rich in arginine and the sulphur-containing amino acids[20]. Egg white proteins are richer than whole egg proteins and egg yolk proteins in the sulphur-containing amino acids, tryptophan, phenylalanine and threonine, but not in the basic amino acids[23]. Whole egg white protein[18] and its principal constituent, ovalbumin,[26] are rich in methionine, while the major yolk protein, ovovitellin, is reported to be rich in arginine, lysine, and leucine[16]. But for a lower cystine content, the proteins of commercial dried whole egg have essentially the same amino acid composition as the proteins of fresh whole egg[23]. The diet of the hen does not seem to have any significant influence on the amino acid composition of the egg proteins[28,29].

Digestibility: Metabolism experiments with rats and human beings have established the very high digestibility of whole egg proteins[5,7,30,31] and of egg albumin[7,31]. Heat treatment is reported to greatly improve the *in vitro* digestibility of egg white proteins[32]. However, their digestibility *in vivo* even in the raw state is of a high order (95 per cent)[33].

Nutritive value: Rat feeding experiments have revealed that whole hen's egg proteins have a higher biological value than the proteins of milk[4-8], meat[4,6-10], soya bean[34], groundnut[7,8] and wheat[4,7-9,34]. Similarly, egg white proteins possess a higher nutritive value than whole egg proteins or yolk proteins[23]. The superiority of whole egg proteins over a number of other dietary proteins[30,31], including milk proteins[12,31,35] in human nutrition has also been demonstrated, but the superiority of egg protein over milk protein is reported to be less pronounced in the nutrition of adult human subjects than of young or mature rats[35]. While with the growing[7,8] or the adult[7] rats, egg albumin is distinctly superior to whole egg proteins, human metabolism study[31] reveals a slight superiority of whole egg proteins over egg albumin; these reverse effects are presumably due to the higher content, in egg albumin, of the sulphur amino acids, required by the rats in greater proportions for hair growth[7].

Processing: Autoclaving does not improve the nutritive value of egg white proteins[33]. While the protein efficiency ratio of commercial processed egg white is of the same order as of fresh egg white that of commercial processed whole egg is significantly lower than of fresh whole egg; this lowering is, however, reported to be unrelated to the lower cystine content of commercial processed whole egg protein as compared to fresh whole egg protein[23].

Supplementary value: The proteins in whole egg and in egg white supplement pork proteins[10]. The gross supplementary value of whole egg[36], egg yolk[36,37] and egg yolk extract[38] to the poor rice diet has been demonstrated, but not that of egg white[36]. Whole eggs have been reported to possess a phenomenal supplementary value to the typical rural diet of Bengal*[39,40]. Supplements to this diet of vegetable origin, such as soya bean[39,40], groundnut[40] and various legumes[40], have been found to give better results when fed in combinations with eggs than when fed alone.

Dried egg: As a source of protein, the most important egg product is the dried egg. The egg-drying industry expanded rapidly during the second world war to meet the requirements of the army[41], but because of its tendency to rapidly deteriorate on storage[41,42],

* The typical rural diet of Bengal is based predominantly on rice; its main difference from the poor rice diet, as consumed by the lower income groups in South India, lies in its containing a small quantity of fish in addition to the other constituents like legumes, vegetables and vegetable oil.

dried egg has not been popular as a rationed article of food[43]. The food value of dried egg is practically equal to that of shell egg[41]. It weighs less (one lb. is equivalent to three dozen liquid eggs), takes up less space and does not break in transport[41]. Dried egg is available in three forms—whole egg, egg white and egg yolk[41]. While dried whole egg is used commercially in making custard, custard pies and baked products, dried egg white finds application in the preparation of angel cakes and confectionery and dried egg yolk, in the preparation of doughnuts and ice cream[44].

Factors involved in dried-egg processing have been reviewed[45]. During storage, except at very low temperatures, dried egg deteriorates by loss of flavour, solubility and beating power; the rate of deterioration is a function of temperature and of water content[42]. At tropical temperatures, a significant fall in the initial quality of dried egg is noticeable even after a week's storage; at low temperatures, however, it is reported to retain good quality and flavour for several months[41]. The effect of moisture content on the initial quality of dried whole egg and on its deterioration in storage[46], the relation between water content and chemical changes during storage[47], and the nature of the reactions leading to the progressive loss of solubility in dried egg[48] have been investigated in detail. Egg, cooked and dried according to a patented process, is claimed to possess a storage life at tropical temperatures longer than that of spray-dried raw egg; after 11 weeks at 97°F, no deterioration is reported to occur at moisture levels below 3.6 per cent[49].

Eggs from other species

Among eggs other than those of the hen, duck's egg has received considerable attention, following the discovery that duck's egg white (Dew) has a lower nutritive value than hen's egg white (Hew)[50]. Though the growth-promoting capacities of Dew and Hew vary according to the season, egg whites collected at comparable periods and tested under comparable conditions have conclusively confirmed the earlier observation that Dew is inferior to Hew in promoting growth in rats[51]. This cannot be attributed to any amino acid deficiency in Dew, because the amino acid compositions of both Dew and Hew have been shown to be similar but for a slightly lower isoleucine content and slightly higher phenylalanine and methionine contents in Dew[24]. Autoclaving (15 lb. pr. for 1 hour) brings about an improvement in the nutritive value of Dew but not in that of Hew[33]. Fractionation studies have shown that the coagulable proteins from Dew and Hew have similar growth-promoting properties, and that the growth inhibition in the case of whole Dew is due to the uncoagulable protein, presumably an ovomucoid[33]. The Dew ovomucoid depresses the growth of rats when fed at 1 per cent level along with different proteins, the most pronounced effect being observed with Bengal gram (chick

pea) protein[52]. Further, *in vitro* liberation from different proteins of amino nitrogen and most of the microbiologically available essential amino acids, particularly histidine, lysine, threonine and valine, is reported to be adversely effected by the presence of DEW ovomucoid[53, 54].

The amino acid composition of the white and yolk of guinea-fowl eggs[55], turtle egg yolk[56] and of roe from different species of Pacific salmon[57] has been investigated. The protein from the egg white of guinea-fowl is exceptionally rich in histidine, whereas the corresponding egg yolk protein is rich in lysine[55]. Turtle egg yolk protein[56] is richer than hen's egg yolk protein in all the essential amino acids except tryptophan and methionine and contains more arginine and cystine than turtle muscle protein. Salmon roe protein is reported to be particularly rich in lysine, threonine and valine[57]. The amino acid composition of roe protein from different species of salmon is fairly uniform age for age, but within each species it is significantly altered with increasing age; while the threonine content decreases with maturity, the arginine and tryptophan levels are fairly constant and the proportions of the other essential amino acids register an increase[57].

TABLE XVII

NUTRITIVE VALUE OF EGG PROTEINS

SOURCE	Protein content: N × 6·25 %	Level of feeding %	Nutritive Value: Biological value %	Nutritive Value: Coefficient of true digestibility %	Nutritive Value: Protein efficiency ratio
Hen's Egg					
Egg, whole[4] ...	...	8	96·0	97·0	...
Egg, whole[9] ...	...	8	93·0	...	...
Egg, whole[30] ...	...	...	97·0*	96·0*	...
Egg, whole[34] ...	...	10	...	...	3·8
Egg, whole, defatted with ether[5] ...	68·9	5 8 8	94·0† 85·0† 97·0‡	97·0† 92·0† 95·0‡	... ...
Egg, whole, dried[6] ...	...	10	...	98·2	4·3
Egg, whole, spray-dried[10]	...	10	...	...	3·8; 3·9
Egg, whole, hardboiled, dried[10] ...	...	10	...	...	3·7
Egg, whole flakes, dried[35]	...	3–4 5 8 8	65·0* 94·0† 85·0† 97·0‡	92·0*	... ...
Egg, whole powder, dried and defatted (commercial)[7] ...	76·8	2–5 10	82·0† 87·0‡	98·0† 97·0‡	... ...
Egg, whole powder, dried and defatted (commercial)[8] ...	76·8	9	...	...	2·8
Egg, whole powder, dried and defatted ... (commercial)[31] ...	76·8	3–5	94·0*	98·0*	...
Egg, whole protein (laboratory sample)[23] ...	...	10	...	...	3·2
Egg, whole protein (commercial sample)[22] ...	...	10	...	...	2·6
Egg, white[58] ...	... ...	5 10	... ...	... ...	2·0 2·6
Egg white, fresh[33] ...	...	10	64·6	94·8	1·2
Egg white, fresh, autoclaved[33] ...	...	10	...	...	1·2
Egg white, hardboiled, dried[10] ...	...	10	...	...	3·7
Egg white, coagulable fraction[52] ...	...	9	...	...	2·1
Egg white, whole, protein (laboratory sample)[23] ...	...	10	...	...	3·5
Egg white, whole, protein (commercial sample)[23]...	...	10	...	...	3·4
Egg albumin[4] ...	...	8	83·0	100·0	...

* determined by human metabolism experiments.

† determined on adult rats. ‡ determined on growing rats.

TABLE XVII. *Nutritive Value of Egg Proteins*

SOURCE	Protein content: N×6·25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Egg albumin, dried and defatted (commercial)[7]	81·6	2–5 10	93·8† 97·3‡	96·0† 100·0‡	... ...
Egg albumin, dried and defatted (commercial)[8]	81·6	9	...	...	3·5
Egg albumin, dried and defatted (commercial)[32]	81·6	3–5	91·0*	101·0*	...
Egg yolk whole protein (laboratory sample)[23] ...	...	10	...	...	3·2
Duck's Egg					
Duck egg white, fresh[33] ...	...	10 11	... 60·8	... 82·5	0·3 ; 0·4 ...
Duck egg white, dried[33] ...	...	10	...	...	2·2
Duck egg white, fresh, autoclaved[33]	...	10 11	... 68·4	... 88·8	2·3 ...
Duck egg white, dried, autoclaved[33] ...	...	10	...	...	2·0
Duck egg white, coagulable fraction[33] ...	...	8	...	...	1·8
Duck egg white, coagulable fraction[52] ...	...	9	...	...	2·2

* determined by human metabolism experiments.

† determined on adult rats. ‡ determined on growing rats.

SOURCE	Protein content %	Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Hens' Egg						
Egg, whole[3] ...	...	6·4	2·1	7·2	4·5	1·5
Egg, whole[19] ...	...	7·0	2·4	6·0	5·0	1·6
Egg, whole[20] ...	...	7·0	2·4	6·0	5·0	1·6
Egg, whole[21] ...	...	9·7	3·6	7·8	...	1·6
Egg, whole[22] ...	...	5·7	2·4	7·3	...	...
Egg, whole[29] ...	...	4·8	3·8	8·1	4·3	1·1
Egg, whole[59] ...	...	6·6	2·4	7·0	4·5	1·5
Egg, whole protein (laboratory sample)[23] ...	82.4	6·5	1·5	5·1	...	1·4
Egg, whole protein (commercial sample)[23] ...	81·3	6·5	1·5	5·1	...	1·4
Egg white[3, 20] ...	...	5·8	2·2	6·5	4·8	1·6
Egg white[24] ...	...	4·2	1·8	5·4	...	1·3
Egg white, whole protein (laboratory sample)[23] ...	90·8	5·6	1·2	4·8	...	1·4
Egg white, whole protein (commercial sample)[23] ...	79.0	6·3	1·3	5·2	...	1·6
Egg albumin[3] ...	...	5·7	2·4	5·0	4·2	1·4
Egg albumin[25] ...	...	5·9	2·3	6·6	...	1·4
Egg albumin[59] ...	...	6·1	2·4	6·5	4·2	1·5
Ovalbumin[16] ...	...	5·4	1·8	5·1	4·3	1·7
Ovalbumin[26] ...	98·5	5·7	2·4	6·3	3·7	1·2
Ovoconalbumin[16] ...	...	5·1	2·5	6·4	4·9	5·7
Ovoglobulin[16] ...	...	4·7	1·4	5·7	4·2	4·1
Ovomucoid[16] ...	...	5·6	4·0	1·6	4·7	2·2
Egg yolk[3] ...	...	8·2	2·6	...	5·3	1·6
Egg yolk[59] ...	...	7·2	1·5	5·7	5·6	1·5
Egg yolk, whole protein (laboratory sample)[23] ...	79·9	7·0	1·5	5·8	...	1·2
Ovolivetin[16] ...	...	5·8	1·4	5·5	5·1	1·7
Ovovitellin[16] ...	...	8·6	1·9	5·9	5·1	1·4
Vitellin[3] ...	...	8·4	1·9	5·8	5·3	1·3
Egg shell membrane[59] ...	...	8·6	0·8	3·5	2·5	2·5
Ovokeratin[16] ...	...	12·9	4·2	5·2	3·3	2·7
Eggs from other species						
Duck egg white[24] ...	...	3·4	2·1	5·7	...	1·2
Guinea-fowl egg white[55] ...	...	11·3	8·1	8·5	...	...
Guinea-fowl egg yolk[55] ...	...	4·9	2·6	11·1	...	...
Salmon egg[3] ...	...	6·4	2·7	3·8	4·0	0·8
Salmon roe (species Chum)[57] ...	...	6·6	2·8	8·7	...	0·9
Salmon roe (species Coho)[57] ...	...	6·9	2·6	8·3	...	0·9
Salmon roe (species King)[57] ...	...	7·5	2·5	8·3	...	0·9
Salmon roe (species Pink)[57] ...	...	6·9	2·9	8·8	...	1·0
Salmon roe (species Sockeye)[57] ...	...	7·2	2·7	8·2	...	1·0
Turtle egg yolk[56] ...	26·2	7·6	2·2	7·0	4·9	1·1

* (C: Chemical; M: Microbiological;

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ACIDS							
Phenyl-alanine %	Cystine %	Methio-nine %	Threonine %	Leucine %	Isoleucine %	Valine %	Method of estima-tion*
6·3	2·4	4·1	4·9	9·2	8·0	7·3	MM
5·6	2·1	3·0	4·9	19·0	5·3	4·4	MM
5·6	2·1	4·0	4·9	19·0	5·3	4·5	MM
6·1	...	3·9	4·9	9·7	7·0	7·2	MM
5·4	...	3·1	5·3	9·2	6·7	7·1	M
...	0·5	...	...	...	...	...	C
6·3	2·4	4·0	4·3	9.2	7·7	7·2	MM
4·5	2·4	3·9	3·8	...	...	...	C
4·9	1·7	4·0	3·9	...	...	...	C
5·5	2·3	4·4	...	...	...	...	MM
4·5	...	3·8	5·2	7·7	6·2	6·1	MM
5·4	2·9	4·2	4·1	...	...	...	C
5·3	2·6	4·0	4·4	...	...	...	C
6·4	2·9	5·5	3·8	9·4	7·1	7·3	MM
7·9	...	4·1	3·6	9·2	7·0	7·0	M
7·5	2·4	5·5	4·2	9·4	7·5	6·4	MM
5·2	1·2	5·0	3·5	12·5	...	5·5	...
7·7	1·9	5·2	4·0	9·2	7·0	7·1	MM
...	3·4	...	...	...	...	...	...
...	...	...	...	...	...	...	...
4·0	6·2	1·7	...	4·0	...	...	...
5·7	1·9	3·0	...	...	...	...	MM
4·4	1·9	3·0	3·5	...	...	...	MM
3·7	2·0	3·6	3·6	...	...	...	C
2·0	3·2	2·4	...	10·6	...	9·8	...
1·5	1·2	2·9	4·9	10·0	...	2·1	...
...	1·8	3·1	4·9	...	...	...	MM
2·6	12·2	4·7	5·2	...	...	...	MM
...	12·7	...	...	7·4	...	1·1	...
5·3	...	4·6	5·6	7.9	4·7	6·2	MM
...	5·0	...	...	...	...	...	C
...	4·8	...	...	...	...	...	C
5·3	1·1	3·0	4·5	10·7	9·9	9·4	MM
5·0	...	2·8	6·3	9·6	7·3	7·5	M
4·8	...	2·6	6·1	9·8	6·7	7·0	M
4·7	...	2·9	5·8	9·2	6·6	6·8	M
4·9	...	2·8	6·1	10·3	7·3	7·3	M
4·7	...	2·7	5·9	10·0	6·8	7·2	M
4·6	2·5	2·5	...	...	...	...	M

MM: Miscellaneous).

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CHAPTER X

FISH

SINCE water covers more than two-thirds of the earth's surface[1] and is far more productive of food than land[2-4], fish constitutes one of the cheapest and most abundant sources of protein for the human race[4-6]. Neither the fishing industry[6], nor the population of fish[7] is uniformly distributed over the different areas of the earth. While more than 90 per cent of the entire fish catch is taken from the waters of the Northern Hemisphere, the far greater expanse of the Southern Hemisphere is exploited only to a limited extent[1]. The areas of intense fishing lie along the north Atlantic seaboard and around Japan[7]. Japan, Korea, United Kingdom, United States, Russia, Norway and Germany are foremost among the fishing nations[7]. Fish ranks only second to rice as food in the Philippines[8] and is the chief source of proteins in the dietaries of the inhabitants of the Philippines[9], Indonesia[10], Malaya[11], central Spain[12] and the Amazon valley[13]. During the second world war, the people of Norway[14] and Newfoundland[15] were able to maintain their consumption of protein at a satisfactory level mainly through increased use of fish in their diet.

Marine culture is remarkably simple and seems to offer something in return for almost nothing—or at least, only very little, in comparison with the effort needed to raise food on land[1]. Even so, the immense water expanse of the earth has received only a disproportionate amount of attention as source of human food[1]. Fishing, in spite of being man's oldest occupation[1,7], is also his least developed one[1] and is confined mainly to the shallow waters along the edges of the continents, while the potential productivity of vast areas of the oceans remains relatively unexploited[1]. The present annual world production of 26 million metric tons of fish and shellfish constitutes only about 2 per cent of the total food consumption of the world[1]. It is reckoned that even in Britain, where normally more fish is consumed than meat[7], the entire catch of fish is sufficient to provide only 10 per cent of the animal protein or 5 per cent of the total protein in the dietary of the population[16]. The annual *per capita* consumption of fish in Britain is reported to be of the order of 35-39 lb.[4,7] and this is less than that in Japan[4] or Sweden[7], but two to three times that in the United States[4,7]. Consumption of fish in India is comparatively very low, being of the order of only 4 lb. per head per annum[17]. Bulk of the consumption is by the inhabitants of the north eastern provinces of Assam, Bengal, Bihar and Orissa and the coastal belt of peninsular India[18]. One of the chief recommendations of the Famine Enquiry Commission (1945) for the improvement of the diet of the Indian people was to extend

considerably the fishing industry[19]. Increased production and consumption of fish have been advocated as the best means of improving the dietaries also of the African natives[5, 20, 21], Fijians[22], Hungarians[23] and Peruvians[24].

The consensus of opinion is that the catch of fish can be increased to the desired extent, provided a market is created and the technical know-how and facilities regarding modern methods of its preservation and processing are made available to the under-developed areas[4, 6]. Fish is a heavy yielder and a mussel (*Mytilus edulis*) farm can produce 20 to 30 times as much food as the best pasture land[1, 7]. Further, it is considered unlikely that a condition would ever arise in which sufficient quantity of fish can be taken away from the waters of the earth to produce a detectable decrease in the marine population[2]. Development of inland fisheries also holds immense potentialities for increasing fish production[1, 19, 22]. Annual yields as high as 8000 lb. per acre have been achieved commercially in fresh-water fish culture, and the view has been expressed that the output of fresh-water fish can be easily quadrupled by adopting suitable farming methods[1]. Carp culture in paddy fields is widely practised in Japan[25] and Indonesia[26], while it is reported that the salt water ponds in the latter country provide annually an additional 15,000 metric tons of fish[26].

Protein Content: The protein contents of fish and fish products are presented in Table XIX. The protein content of fresh water fish is reported to vary from 13.7 per cent to 25.2 per cent [16, 23, 27-33]; of marine fish, from 9.1 per cent to 26.1 per cent[16, 30, 32, 34-41]; of shellfish and crustacea, from 9.8 per cent to 24.8 per cent[32, 34-36, 40, 42-44]; of dried fish, from 44.0 per cent to 70.9 per cent[29, 41, 42, 45-47]; of salted and dried fish, from 27.8 per cent to 80.0 per cent[38, 48]; and of fish meals, from 11.6 per cent to 93.0 per cent[1, 49-58]. Most of the so-called cheap and despised varieties are richer in protein than the costly and delicious ones[34, 36] and have the additional advantage of being available all the year round[36]. 'Mahasole'[30] (*Barbus tortor*), 'Singhi'[31] (*Saccobranchus fossilis*), 'Hilsa'[31] (*Clupea ilisa*) and 'Ruhee'[33] (*Labeo rohita*) among fresh water fish, tunny or 'Sooda'[34] (*Thynnus macropterus*), seer fish or 'Aya kora'[34] (*Cybium guttatum*), silver bellies or 'Karalu'[37] (*Leiognathus* sp.), mullet or 'Bonthalu'[37] (*Mugil speigleri*), shark or 'Mushi'[36] or 'Sravu'[34] (*Carcharius limbatus; Carcharius lacticaudus*) and hammerhead shark or 'Kan mushi'[36] (*Sphyrna blochii*) among marine fish, Indian Chank[42] (*Xancus pyrum*) among shellfish and crustacea and 'Halda chingri'[48] (factory-cured) among salted and dried fish are rich sources of protein. While the protein content of 'Koral' meal[50] is reported to be as high as 93 per cent, that of edible white fish flour[58] is reported to be 89 per cent. Whole herring meal, prepared without removal of the stickwater, is characterised by a higher content of soluble proteins as compared with ordinary herring meal[59, 60]. The body organs

of eels[39] (*Anguilla anguilla*) and whales[61] (*Cetacea* sp.) and fermented fishery products such as fish paste[62, 63] and fish sauce[64-66] are also valuable sources of protein.

From 7.5 per cent to 17.1 per cent of the total nitrogen of most varieties of fish is contributed by non-protein constituents[35, 67]. Exceptions are prawns[35] (*Peneus menoder*) and 'Pakat'[35] (*Dasyatis zugei*) in which the non-protein nitrogen (N.P.N.) is 24.3 per cent and 37.9 per cent respectively of the total nitrogen. The pattern of distribution of free amino acids in the N.P.N. fraction has been shown to vary with the family to which the particular species belongs[35, 68, 69].

Amino acid composition: The amino acid composition of the proteins of fish and fish products is presented in Table XXI. In general, fish proteins contain all the essential amino acids in adequate amounts and in balanced proportions[70-87] and in this respect resemble other proteins of animal origin[72, 74, 75, 81, 88-91]. As such, fish can replace chicken, pork, beef, lamb or veal as source of animal protein in the human diet[89]. As a class, fish proteins are valuable sources of lysine[70, 72-77, 82, 83, 86, 87, 89, 92-96] and methionine[70, 72-75, 77, 79-82, 86, 87, 89, 90, 92, 93, 97-102]. Special mention may be made of a few varieties, the proteins of which are remarkably rich in these two essential amino acids, containing more than 12 per cent lysine[72, 77, 82, 83, 92, 96] or 4 per cent methionine[72, 73, 98]. The histidine content of fish proteins is highly variable[75], being higher than 5 per cent in some varieties[74, 75, 98, 103] and lower than 1 per cent in certain others[11, 83, 85, 92]. The proteins in certain species of fish of Indian origin are reported to be very low in arginine[104]. There is no essential difference in the amino acid composition of the proteins of fish and shellfish[72, 74, 75, 79, 89, 93]. Among fishery bye-products, the proteins of cod (*Gadus morrhua*) liver[82] are well balanced with respect to all the essential amino acids, in contrast to those of fish solubles[76, 82, 84], whale solubles[105], fish stickwater[76, 79, 82, 83, 106] and glue water from whale blubber[105].

Nutritive value: Fish proteins are reported to possess a high digestibility[32, 33, 50, 107-111], biological value[33, 50, 107-115] and growth-promoting value[33, 50, 81, 116-120]. Whale meat proteins[57] are readily digested by pepsin *in vitro*. Among seven commercial samples of American fish meals prepared from different species of fish, only the proteins of anchovies (*Engraulis encrasicholus*) meal and crab (*Scylla serrata*) meal possess a low digestibility[111]. The biological values of the proteins in all these fish meals are uniformly high[111], as also those of the proteins in different species of Indian fish[33, 50, 107] and shellfish[107]. The biological values of the proteins of different Chinese[108, 109, 117] and Canadian[119] fish and South African fish meals[110, 112], however, vary to a considerable extent. The nutritive value of haddock (*Gadus aeglefinus*) meal proteins is higher than that of menhaden (*Brevoortia tyrannus*) meal proteins[114] and that of herring (*Clupea harengus*) stick-

water proteins is reported to be very low as compared to that of the proteins of ordinary herring meal[121]. In respect of nutritive value, fish proteins are in the same class as chicken proteins[81, 116], being inferior to whole egg proteins[111] or skim milk proteins[111], but slightly superior to beef proteins[81, 116, 119], egg albumin[119] and casein[118, 119]. Fish proteins are about equal to casein[118] in promoting plasma protein regeneration in depleted rats and are slightly superior to casein[118] and skim milk proteins[122] in promoting haemoglobin regeneration.

Processing: Canning[74, 75, 81, 87], broiling[81] or treatment with high-voltage cathode rays[95] do not bring about any significant alteration in the amino acid composition of fish proteins. On the other hand, the effect of dehydration on their amino acid composition is a subject of controversy[81, 87]. Heating at 300-320°F for 3 hours or flame drying at a temperature of 220°F is reported to impair the availability of essential amino acids[77, 78] in general and lysine[96] in particular. Drastic conditions in the preparation of protein concentrates by alkali digestion of herrings bring about the destruction of most of the cystine and part of the lysine and methionine, thereby adversely affecting the nutritive value of the herring protein[101].

Smoking[123] or different methods of drying[124, 125] have no effect on the digestibility of fish proteins, but cooking[123] is reported to increase their digestibility slightly. The biological value of fish proteins, like that of soya bean proteins, increases with moderate heat-processing, but decreases with drastic heat treatment[54]. Defatting and deodourisation, whereby fish meals are converted into edible fish flours, do not appreciably lower the biological value of their proteins[127]. While short exposure of fish proteins to high temperatures is not necessarily harmful[96, 126], prolonged exposure is definitely injurious[54, 96, 125] and it is preferable not to exceed a temperature of 100-110°F[96, 125]. The superiority in nutritive value of the proteins of vacuum-dried[114, 128-130] or steam-dried[128-130] fish meals over those flame-dried[114, 128-130] has been demonstrated by a number of workers. Sun drying[33] is reported to possess an advantage over steam drying in so far as the nutritive value of the proteins in fish meals is concerned, but it is a point of controversy as to whether vacuum drying[128, 130] possesses any such advantage over steam drying. The nutritive values of the proteins of pressure-evaporated and vacuum-evaporated stickwater concentrates are of the same order[121].

Supplementary value: The gross supplementary value of fish meal to a poor South African native diet has been shown to be of the same order as that of milk powder[5]. Fish proteins possess an appreciable supplementary value to the proteins of bread[110] and of legumes[33], but not to rice proteins[55]. The nutritive values of the proteins in ordinary fish meal and whole fish meal (with solubles) are of the same order[111, 121] and both are very much higher than the nutritive value

of stickwater protein[121], indicating a supplementary relationship between the soluble and insoluble moieties of fish proteins.

Preservation

Larger catches of fish would be of little value in the context of increased protein intake by the population unless cheap and reliable methods of preservation are adopted, enabling efficient distribution to outlying areas far from the fishing centres[1, 131]. As a class, fish are extremely perishable as compared to foods of terrestrial origin[1, 7]. This is due to the effective biological control of the powerful enzyme systems in live fish ceasing to function as soon as they are taken out of water[1]. Landed fish are subject to three types of deteriorative changes: those brought about by microorganisms, enzyme action (autolysis) and chemical action (mainly on the fatty constituents)[132]. The spoilage is especially rapid in hot and damp climates[131]. The purpose of all methods of fish preservation is to prevent, or, at any rate, greatly retard bacterial, enzymatic and chemical decomposition[1]. They comprise salting, drying, smoking, canning, freezing and treatment with antibiotics or ionizing radiations[1]. Among these, salting, drying and smoking, being comparatively cheap and easy to carry out, are most widely followed in the under-developed countries[131].

Salting: Salting of fish is practised both by itself[8, 9, 20, 131, 133-135] and as a prelude to other methods of preservation, notably drying[20, 26, 131, 136-144] and smoking[144-146]. Different techniques[8, 20, 131, 134, 135] like kench salting, dry salting or brining are employed, depending on the size and type of fish[20, 131, 134] and the climatic conditions[20]. Dry salting is reported to cause coagulation of the fish proteins[123]. Purity of the salt is an important factor in determining quality of the salted fish[9, 20, 131], while the salt concentration influences its storage life[9, 133].

Drying: Fish, dried without previous salting, keep better than salted and dried fish, because they have less tendency to absorb moisture[131, 140]; it is, however, often necessary to salt the fish before sun drying (beach drying) in order to prevent spoilage during the drying process itself[135, 140]. Though sun drying is extensively practised particularly in the Indo-Pacific regions[8, 9, 42, 131, 135, 137, 140, 141, 147], by its very nature it is a slow and unreliable process[137, 139, 143] and often leads to products of inferior quality[45, 48]. However, the *peda Siam* (*Scomber neglectus*, *Scomber kanagurtha*), a salted sun-dried fish of considerable commercial importance in Thailand, is highly valued for its organoleptic and keeping qualities[131]. Sun-dried prawns are also reported to possess a satisfactory consumer appeal and shelf-life[147].

Artificial dehydration[139] is a distinct advance on sun drying in that it provides for effective control over factors like humidity, air flow and temperature. Fish have been successfully dried by forced draft air

drying[134, 138, 148], roller drying[148], flame drying[149], cabinet drying[81, 141, 142], pneumatic drying[149], freeze drying[148] and also by infrared heating[138, 150]. Mechanical dewatering of fish prior to dehydration is reported to result in appreciable reduction of load on the drier[151]. While unsalted fish can tolerate fairly high temperatures[134, 138, 148] during dehydration, it is advisable not to exceed a temperature of 80°F[136, 138] in the case of salted fish to avoid formation of impervious salt-protein crusts[136]. A novel development of considerable interest to the consumer is the vacuum-contact or 'Pressfisk' process which enables fish to be dehydrated in the form of whole fillets instead of mince[1, 152, 153]. As a rule, dried fish products keep less well in the hot, damp, tropical climate than they do in colder and/or drier regions[131]. However, some samples have been reported to keep for 6 to 9 months even under tropical conditions without becoming too unpalatable[154] and their storage life can be lengthened by packing in vacuum[134] or inert gas[134, 148], or by decreasing the temperature of storage[154].

Smoking: Depending on the type of product desired, smoke curing[9, 138, 146, 155] of fish involves salting, drying, heat treatment (in the case of hot smoked products[8, 134, 146] only) and smoking. Its preservative action[154] on fish is mainly due to the deposition of tars and oils from the smoke in the form of minute particles[156]. These smoke constituents contain unidentified phenolic substances[156], which have been shown to possess pronounced antioxidant properties, especially in conjunction with vitamin C as the synergist[157]. Smoking by dipping fish in solutions of smoke oils, instead of direct exposure to smoke, has been advocated as a method of achieving uniformity in the quality of smoked products[156]. Various suggestions have also been put forward for improving the design of smoking kilns[138, 158]. The shelf-life of smoked fish depends not only on the smoke uptake[134, 155], but also on the degree of salting[134, 145, 155] and drying[134, 145, 155] and has been reported to vary from a few hours[134, 135, 145] to a few months[135, 137]. Products such as fish wood (Tuna wood), dried and smoked under drastic conditions, have been reported to keep for a year or longer under tropical conditions[159].

Canning and Freezing: Both canning[74, 75, 81, 143] and freezing[81, 160, 161] are no doubt elegant methods of fish preservation widely practised in Europe and America, but are far too costly to suit the economy of the under-developed regions of the world[9, 131]. In fact, the inhabitants of South East Asia could not afford even the very cheap Japanese canned fish products available in the area before the outbreak of the second world war[131]. The chances of freezing becoming a popular method of fish preservation in these regions are also remote in view of the fact that frozen fish requires refrigeration at very low temperatures throughout storage[161]. When fish is slowly frozen or frozen fish is stored at too high a temperature, denaturation of the

proteins can take place, resulting in the separation and loss, on thawing, of considerable liquid (drip) containing valuable soluble proteins[123].

Preservation with antibiotics and ionizing radiations: Methods of preserving fish with antibiotics[162], or ionizing radiations[132, 163, 164] are yet in the experimental stage and the feasibility of their application on a commercial scale still remains to be determined. The well known preservative action of seaweed fronds on fish has recently been traced to the antibiotics present in them[1]. The relative efficacy of different antibiotics under a variety of conditions has been investigated[165-169]. Ionizing radiations do not produce appreciable flavour change in fish[95, 170, 171] and provide an excellent means of sterilizing packaged fish fillets without the application of heat[132].

Utilisation

Fish solubles: Wet reduction of fish and fish waste for the production of meal and oil involves essentially the twin steps of cooking and pressing and gives rise to considerable quantities of stickwater[1, 172-175]. This contains bulk of the water-soluble fish proteins, which have been reported to vary from 18-20 per cent of the total proteins in some samples of fish to as much as 40 per cent in others[46, 176]. After adjustment of the pH to 4.5 with sulphuric acid and subsequent clarification (Sharples—Lassen process[1, 173, 177, 178]), fish stickwater can be concentrated to a thick syrup of 40-50 per cent solids content, known as condensed fish solubles[1, 172, 173, 175, 177]. The concentration may be carried out both under pressure[121, 177-179] and under vacuum[121, 175, 177, 180]. In view of their fluid nature, condensed fish solubles are difficult to handle and store[178, 180] and recent trends in their utilisation are either incorporation into the rest of the press cake to produce whole fish meal[121, 172, 173, 176-181] or dehydration into powdered form[177, 178, 180]. In the Lysosund process[176, 177], which is held to be economically most profitable[182], the quantity of stickwater is kept at the barest minimum by resorting to indirect cooking with steam[176, 183] and the thick stickwater is mixed with the press cake and dried. The main technological problem in the preparation of dried fish solubles is the intractable glue formed in the final stages of drying[180]. Dried fish solubles prepared according to conventional methods of dehydration have been reported to be highly hygroscopic and hence difficult to package[177], unlike the product prepared by the process of chemical precipitation of fish solubles from stickwater[184].

Fish meal and fish flour: Large quantities of fish meal are produced in different parts of the world from surplus fish[172, 174, 183, 185-187], inedible fish (chiefly menhaden[1, 175]), or filleting waste[1, 174, 175, 185-187] (which is reported to form anything up to 70 per cent of the fresh weight depending on the species of fish[1, 16, 34, 36]). Both the dry[53, 172, 173, 175, 188] and wet[53, 172-174, 175, 183, 186, 188, 189] reduction methods

are equally applicable to lean fish but not to fatty fish which necessarily require to be cooked and pressed for the removal of the oil[172, 173, 183, 185]. The advantages claimed for wet reduction are the production of fish meals with a longer shelf-life under tropical conditions of storage[186] and decreased load on the drier caused by the separation of considerable quantities of water during pressing[172]. In recent modifications of the wet reduction process[173] (Flesland[177], Nygaard[177, 183] and Notevaarp[183] processes), the raw material is dried to a low moisture content prior to the oil extraction in order to avoid or reduce stickwater formation. Improved methods for deodorising fish meal[190] and for treating fish offal such as cod liver for the production of protein-rich meal[191, 192] have been described. Fish meal drying can be carried out either in the sun[53, 186, 188], or by direct[172, 175, 183, 187, 193], or indirect[172, 175, 187] heat driers, operating in batch[185], continuous[185, 187] or batch-continuous[185, 187] units. Solvent extraction as a method for the production of high quality fish meals is also coming to the fore[51, 177, 183, 194-196], particularly the azeotropic[183, 189] (VioBin[197]) process in which dehydration and oil extraction are carried out simultaneously.

It is being increasingly realised that fish meal would form an ideal protein supplement to human diets[125, 198-201], particularly of the vulnerable sections of the population[186, 199, 201, 202]. Of the one million tons of fish meal now being produced in the world, 30-40 per cent, by the most conservative estimate, can be used for feeding infants and children[202]. Fish flour[1, 58, 200, 201, 203-205] is the popular name for fish meal prepared (invariably by an extraction process[110, 203]) with sufficient care as to render it fit for human consumption. Edible fish flour is produced on a commercial scale in South Africa[199, 201, 203, 204, 206, 207], West Africa[206], East Africa[201], Norway[1], Iceland[201], United States[207], Brazil[205], Chile[201], Indonesia[200], Thailand[200] and Japan[200]. Its cost of production is reported to compare favourably with that of other protein rich foods of animal origin, such as skim milk powder[201]. Its easy incorporation into wheat flour[207, 208] and maize (mealie) meal[203] specially suits fish flour for widespread use as a protective protein food in the diets of infants who have been shown to tolerate it even at a very young age (3 to 4 months)[201]. The value of fish protein in the prevention and treatment of kwashiorkor has been recognised[1, 205, 209] and feeding experiments with children using recipes containing fish flour have been carried out in several countries[1, 199, 200 201, 207, 210]. Consumer acceptability trials[199-201] have shown that fish flour with a certain amount of residual flavour is preferred in Africa and South East Asia, but not in other parts of the world[201]. It has been used as an enriching component in bread[110, 199, 201, 204, 207, 211], biscuits[1, 200, 201], cakes[201], sweets[200], soups[1, 201] and gruel[1]. Incorporation of fish flour at levels up to 10 per cent does not appreciably alter the taste and appearance of bread[201, 204, 211].

Fish protein: Isolation of protein from waste fish has been advocated as a facile method of augmenting our dietary protein resources[118, 212]. Factors influencing the extraction of fish protein have been studied in detail[213, 214]. Protein has been prepared from different species of fish both on an experimental scale[125, 214, 215] and on a commercial scale[118, 216, 217]. Besides, considerable quantities of herring protein are obtained as a bye-product in the alkali reduction of herring for the production of oil; use of high lye concentrations and digestion temperatures in this process are reported to cause partial breakdown of the protein and thereby to adversely affect both its yield[218] and its nutritive value[101, 219]. Extracted fish protein resembles commercial casein and can be solubilised by treatment with hot dilute alkali followed by acetic acid[217]. Soluble fish albumin (particularly Wiking Eiweiss[52, 220], developed by the Germans during the second world war) is extensively used as an edible egg substitute in confectionery and baked goods.

Fish autolysates: This is another form in which surplus fish can be utilised to advantage as human food[221, 222]. Fermented fish products (fish sauce and fish paste) are obtained by the auto-digestion of fish flesh, mainly by the proteolytic enzymes of its own digestive system[1, 66, 131, 222-224] and also, to a lesser extent, by bacterial proteolysis[66, 131, 222-224]. The method of preparation essentially consists in brining[1, 9, 62, 131, 137, 223, 225, 226] fish for long periods in presence of sufficient salt to inhibit bacterial spoilage[1, 66, 131, 222]. Though primarily a speciality of the East Asian countries[1, 9, 131, 224, 227], they are also produced[223, 224] and consumed[201, 204] in limited quantities in other parts of the world. The most widely known among fish sauces are *nuoc-mam*[1, 66, 131, 137, 222-226] of Indo-China, *nam pla*[131, 226] of Thailand, *patis*[9, 131] of the Philippines, *bakasang*[224] of Indonesia and *moluha*[224] of Egypt; and among fish pastes, *ngapi seinsa*[62] of Burma, *prahoc*[1, 131, 137] of Indo-China, *bagoong*[9, 131, 224] of the Philippines, *trassi*[131] of Indonesia and *kamaboko*[228] and *gyomiso*[229] of Japan. The preparation of fish paste by fermentation of fish meal with *Aspergillus oryzae*[229, 231] is common in Japan; during this process, the odour of fish meal is reported to be removed and its taste, to be improved[200].

Fish hydrolysates: These[232, 233] have been prepared using different acids[149, 222, 234, 235], as well as caecal enzymes[1, 236] of the fish, but whether alkali[52, 212, 222, 234] is an equally suitable agent for breaking down the protein is a subject of controversy. It is possible to reduce the offensive smell of the acid hydrolysates by the addition of dried seaweed[230]. The value of fish hydrolysates as supplement to the diet of convalescents and in the treatment of cases of malnutrition, tuberculosis and duodenal and ventricular ulcers has been recognised[52, 212]. They have been used as an enriching component in concentrated broth, soups and sandwich spreads[222].

Whale products: Prior to the second world war, bulk of the whale meat was usually thrown away after extraction of the oil[237]. The war gave considerable fillip not only to the whaling industry by bringing about an increase in the whale meat output from 0.5 million tons[237] to 1.3 million tons[1], but also (in view of the general scarcity of animal foods[238]) to the inclusion of whale products in human diets[238, 239]. Only 30,000 tons[1] of the entire world production of whale meat are reported to have been used for dietary purposes annually in the years following the war, while recent estimates place its consumption in Japan alone at more than ten times this figure[200]. Other countries where whale meat is used as human food include Norway[238] and the United Kingdom[237, 238] and the need for its popularisation has been keenly felt in South Africa[240]. But for its lower fat content, whale meat closely resembles the lean meat of terrestrial animals[237]. As a source of protein, it is stated to be far cheaper than beef and pork[61]. Its quality varies according to the age of the whale, the pale meat of the immature animals being the best[237, 239]. Consumer trials have shown that it is acceptable to children[61]. Incorporation of more than 5 per cent[100] whale meat (particularly from the mature animals[239]) is reported to impart the characteristic whale taste to certain dishes; this can, however, be masked by canning[239] or by the adoption of proper cooking techniques[237]. Frozen whale meat resembles tender beef[237] and is quite popular in the United Kingdom[238].

Zooplankton: Marine zooplankton subsists on phytoplankton[1, 241, 242] (unicellular microscopic autotrophic algae, mainly diatoms and dinoflagellates[1, 242]) and, in its turn, serves as the food of the higher aquatic animals[1, 243]. It is thus the connecting link in the food chain that leads from phytoplankton to fishes of different sizes[1, 3, 241, 242], sharks[1, 241] and whales[241, 242, 244]. Zooplankton forms only five to ten per cent by weight of the phytoplankton[3], but by virtue of its larger size, is easier to catch with nets[241, 245]. It consists mostly of copepods[1, 241, 244, 245] (*Centropages* sp.) and krill[242] (*Euphausia superba*), together with smaller percentages of other crustacea, worms, polecypods and fish larvae[245]. Both its composition[246, 247] and abundance[241] are subject to considerable regional, seasonal and diurnal variations. The economic feasibility of collecting zooplankton, in sufficient amounts to warrant its use as human food, is a point of controversy[241, 242, 244]. According to one calculation, however, two fishermen can gather in a day nearly 600 lb. of zooplankton off the Scottish coast, containing sufficient protein to nourish more than 350 persons[244]. The annual production of krill is estimated to be of the order of 1350 million tons in the Antarctic ocean, where it forms the chief food of the whales and it has been suggested on this score that krill-trawling may be more profitable than whaling[242]. Animal feeding experiments have shown that, as the sole article of diet, wet, squeezed zooplankton is not

satisfactory, weanling rats so fed surviving for only four to five days and adult rats for eighteen to nineteen days[245]. However, one-third the standard diet of weanling rats can be replaced by zooplankton without affecting their well-being and rate of growth[245]. The main limitation of zooplankton as human food appears to lie in its high mineral content and mineral imbalance[243, 245], rather than in the quality[241] or quantity[242, 244, 245] of its protein. On dry weight basis, it contains 52-59 per cent protein[3, 241, 344, 245]. Zooplankton possesses a pleasant shrimp like flavour[244]. Frozen krill too is reported to be quite palatable and no untoward after-effects have been experienced following its consumption[242].

TABLE XIX

PROTEIN CONTENT OF FISH AND FISH PRODUCTS

NAME		Locality	Protein Content: N × 6·25 %	Moisture Content %
Fresh water fish				
'Air' (*Arius arius*)[27]	...	Bengal	15·9	78·1
'Bacha' (*Chpisoma garua*)[27]	...	,,	18·1	78·8
'Bachwa' (*Clupısoma garua*)[28]	...	Bihar	18·1	76·4
'Bam'[27]	...	Bengal	16·1	74·8
'Baspata machli' (*Allia celia*)[29]	...	Bihar	18·2	76·1
'Bata' small variety (*Labeo bata*)[30]	...	Bengal	14·3	79·0
'Bele' (*Glassgobius giuris*)[31]	...	,,	14·5	79·7
'Bhangar' (*Mugil tade*)[30]	...	,,	18·9	76·3
'Bhangar'[31]	...	,,	14·8	70·6
'Bhangar bata'[31]	...	,,	19·4	67·3
'Bhetka' (*Lates calcifer*)[31]	...	,,	13·7	82·0
'Bhole' (*Sciacna coitor*)[27]	...	,,	15·2	78·1
'Bhoona'[28]	...	Bihar	17·6	77·3
'Boal' (*Wollago attu*)[31]	...	Bengal	15·4	73·0
'Bowari machli' (*Wollago attu*)[29]	...	Bihar	21·7	75·9
'Bugda chingri'[31]	...	Bengal	18·8	73·0
Brown trout (*Salmo fario*)[16]	...	Britain	18·8	78·8
'Chela' (*Chela bacaila*)[30]	...	Bengal	14·6	77·5
'Chappal' (*Notopterus chitala*)[32]	...	West Pakistan	18·9	73·3
'Chital' (*Notopterus chitala*)[30]	...	Bengal	18·6	75·0
'Dhain' (*Silonia silundia*)[27]	...	,,	14·0	72·0
Eel (*Anguilla vulgaris*)[16]	...	Britain	14·4	60·0
'Fesha'[31]	...	Bengal	18·4	74·0
'Folui' (*Notopterus notopterus*)[31]	...	,,	19·8	73·0
'Gurjowli'[30]		,,	16·1	81·0
'Hilsa' (*Clupea ilisa*)[31]	...	,,	21·8	53·7
'Hilsa'[35]	...	,,	19·7	...
'Kalabasu' (*Labeo calabasu*)[31]	...	,,	14·7	81·0
'Katla' (*Catla catla*)[31]	...	,,	19·5	73·7
'Katla'[27]	...	,,	18·6	74·2
'Kharsala'[27]	...	,,	16·3	75·3
'Kholshe' (*Colisa fasciati*)[30]	...	,,	16·1	75·0
'Khoyra'[31]	...	,,	18·0	72·0
'Koi' (*Anabus testudineus*)[31]	...	,,	14·8	70·0
'Kuja vetki'[31]	...	,,	18·9	72·0
'Lata' (*Ophiocephalus punctatus*)[31]	...	,,	19·4	74·0
'Magur' (*Clarius batrachus*)[31]	...	,,	15·0	78·5
'Mahasole' (*Barbus tortor*)[30]	...	,,	25·2	70·3
'Manguri machli' (*Clarius magur*)[29]	...	Bihar	21·1	73·8
'Mowrala' (*Amblypharyn godonmola*)[31]	...	Bengal	18·0	72·0
'Mrigala' (*Cirrhina mrigala*)[31]	...	,,	19·5	75·0

TABLE XIX. *Protein Content of Fish and Fish Products*

NAME	Locality	Protein Content: N × 6·25 %	Moisture Content %
'Pabda'[27] ...	Bengal	19·2	73·0
'Pakal'[27] ...	,,	14·3	76·8
'Pangas' (*Pangasius pangasius*)[27] ...	,,	14·2	72·3
'Parsey' (*Mugil parsia*)[31] ...	,,	16·6	69·3
Perch (*Perca fluviatilis*)[16] ...	Britain	17·6	80·4
'Puti'[31] ...	Bengal	18·1	75·0
'Rehu' (*Labeo rohita*)[23] ...	Bihar	17·8	78·1
'Rehu'[31] ...	Bengal	16·6	76·7
'Rohu'[27] ...	,,	15·2	77·1
'Ruhee' (*Labeo rohita*)[33] ...	,,	23·3	...
'Royna'[27] ...	,,	15·6	76·0
Salmon (*Salmo salar*)[16] ...	Britain	21·5	66·6
'Sarputi' (*Barbus sarana*)[27] ...	Bengal	16·5	70·2
'Singhi' (*Saccobranchus fossilis*)[31] ...	,,	22·8	68·0
'Sole' (*Ophiocephalus striatus*)[31] ...	,,	16·2	78·0
'Tengra'[31]	,,	19·2	70·0
Marine fish			
'Amlet'[30] ...	Bengal	20·8	73·5
Anchovy or 'Manangu' (*Engraulis mystax*)[34] ...	Kerala	19·3	69·3
Bass (*Labrax lupas*)[16] ...	Britain	19·3	77·0
'Bhakas'[35] ...	Bombay	22·5	...
'Bhalu'[35] ...	,,	19·4	...
Bombay duck or 'Bombil' (*Harpodon nehereus*)[36] ...	,,	9·1	89·3
Bombay duck or 'Bombil'[32] ...	West Pakistan	9·1	89·3
Bream (*Sparus centrodontus*)[16] ...	Britain	17·6	78·8
Cat fish or 'Jellalu' (*Siluridoe* sp.)[37] ...	Andhra	21·4	77·1
Cat fish or 'Singhada' (*Arius dussumieri*)[38] ...	Bombay	20·9	61·0
Cat fish or 'Shingala'[36] ...	,,	12·7	78·1
Cat fish or 'Shingala'[32] ...	West Pakistan	12·7	78·1
Cat fish or 'Vallial etta'[34] ...	Kerala	17·4	79·7
Cat fish (*Anarrhichas lupus*)[16] ...	Britain	17·0–19·7	78·1
Cockup or 'Bhekti' (*Lates calcarifer*)[32]	West Pakistan	13·7	82·0
Cockup or 'Kajura'[38] ...	Bombay	12·6	79·4
Cockup or 'Khajura' (large)[35] ...	,,	19·7	...
Cockup or 'Khajura' (baby)[35] ...	,,	19·7	...
Cockup or 'Narimeen'[34] ...	Kerala	18·4	78·2
Cod (*Gadus morrhua*)[16] ...	Britain	15·0–19·0	80·3–82·6
Conger eel (*Conger vulgaris*)[16] ...	,,	19·1	79·6
Dab (*Pleuronectes limanda*)[16] ...	Britain	12·8–18·2	79·1
'Dagol' (*Chorinemus toloo*)[36] ...	Bombay	21·2	72·2
'Dangoori'[25] ...	,,	20·6	...
'Dhoma' (*Scioena glauca*)[36] ...	,,	19·0	78·3
'Dhoma'[32] ...	West Pakistan	19·0	78·3
'Dhomi'[35] ...	Bombay	17·5	...
Dogfish (*Acanthias vulgaris*)[16] ...	Britain	19·6	75·1
Eel or 'Wam' (*Muraenesox talabonoides*)[36] ...	Bombay	16·9	80·0

TABLE XIX. *Protein Content of Fish and Fish Products*

NAME		Locality	Protein Content : N × 6·25 %	Moisture Content %
Eel or 'Wam' [35]	...	Bombay	16·9	...
Eel, elvers (*Anguilla anguilla*)[39]	...	Britain	12·6	81·8
Eel, snigs[39]	...	,,	19·0	76·5
Eel, yellow[39]	...	,,	17·2	70·8
Eel, silver[39]	...	,,	15·6	59·7
Eel muscle, yellow[39]	...	,,	16·6	71·3
Eel muscle, silver[39]	...	,,	14·4	57·1
Flounder (*Pleuronectes flessus*)[16]	...	Britain	16·8	81·3
'Golavindalu'[37]	...	Andhra	20·3	78·1
'Gurnards' (*Trigla* sp.)[16]	...	Britain	19·7–20·2	76.0–77·2
Haddock (*Gadus aeglefinus*)[16]	...	Britain	14·6–20·3	79·1–84·1
Hake (*Merluccius vulgaris*)[16]	...	,,	17·8–18·6	79·5
Halibut (*Hippoglossus vulgaris*)[16]	...	,,	18·0–18·8	75·4–79·0
Hammerhead shark or 'Kan mushi' (*Sphyrna blochii*)[36]	...	Bombay	23·9	75·1
Herring, Indian or 'Kannan mathi' (*Pellona brachysoma*)[34]	...	Kerala	20·3	72·8
Herring, Ox-eyed or 'Valathan' (*Megalops Cyprinoides*)[34]	...	Kerala	20·7	74·7
Horse mackerel or 'Chamban' (*Caranx crumenophthalmus*)[34]	...	Kerala	18·7	76·9
Horse mackerel or 'Katbangda'[36]	...	Bombay	20·2	76·5
Horse mackerel or 'Ovupara' (*Caranx malampygus*)[34]	...	Kerala	21·2	76·9
Horse mackerel or 'Para' (*Caranx* sp.)[37]	...	Andhra	21·0	76·0
Jew fish or 'Ghol' (*Sciaena sina*)[36]	...	Bombay	17·3	77·4
Jew fish or 'Ghol' (*Sciaena miles*)[28]	...	,,	18·4	69·7
Jew fish or 'Gorasalu' (*Scioenidoe* sp.)[37]		Andhra	18·1	80·2
Jew fish or 'Kora' (*Pseudoscioena coiber*)[34]	...	Kerala	18·8	78·3
Jew fish or 'Pallikora' (*Otolithes ruber*)[34]	...	Kerala	20·0	77·0
'Jipti'[35]	...	Bombay	20·6	...
John Dory (*Zeus faber*)[16]	...	Britain	18·4	78·0
'Katari'[35]	...	Bombay	21·3	...
'Lady vendi' (*Sillago sihasna*)[30]	...	Bengal	18·2	77·0
Lemon sole (*Pleuronectes microcephalus*)[16]	...	Britain	16·4–18·4	78·9
Ling (*Molva vulgaris*)[16]	...	,,	19·5–22·2	78·3
Mackerel or 'Aila' (*Rastrelliger kanagurta*)[34]	...	Kerala	18·9	77·3
Mackerel or 'Bangda'[35]	...	Bombay	18·1	...
Mackerel or 'Bangda'[32]	...	West Pakistan	20·2	76·5
Mackerel or 'Tel-bangda' (*Scombor microlepidotus*)[36]	...	Bombay	19·5	74·7
'Mandela' (*Coilia dussumieri*)[36]	...	,,	14·6	77·1
'Mandali' (*Coilia dussumieri*)[35]	...	,,	17·5	...
Megrim (*Arnoglossus megastoma*)[16]	...	Britain	17·8	80.0
Mud skipper or 'Niwta' (*Boleopthalmus dussumieri*)[36]	...	Bombay	19·4	76·4

TABLE XIX. *Protein Content of Fish and Fish Products*

NAME	Locality	Protein Content: N × 6·25 %	Moisture Content %
Mullet or 'Boi' (*Mugil speigleri*)[36] ...	Bombay	17·8	73·0
Mullet or 'Bonthalu'[37] ...	Andhra	22·6	76·0
Mullet or 'Thirutha' (*Mugil oeur*)[34] ...	Kerala	19·1	69·9
Mullet, grey (*Mugil* sp.)[16] ...	Britain	19·5	75·6
Mullet, red (*Mullus* sp.)[16] ...	,,	19·0	74·9
Oil Sardine or 'Nallamathi' (*Sardinella longiceps*)[34] ...	Kerala	19·6	76·5
'Pakat' (*Dasybatus uarnak*)[36] ...	Bombay	20·0	77·5
'Pakat' (*Dasyatis zugei*)[35] ...	,,	21·9	...
'Palamplate' (*Pampus argenteus*)[30] ...	Bengal	15·1	81·0
'Parsey,' big variety (*Mugil parsia*)[30]	,,	18·4	72·3
Plaice (*Pleuronectes platessa*)[16] ...	Britain	15·7–17 8	80·8
Pollack (*Gadus pollachius*)[16] ...	,,	18·1–19·1	...
Pollona or 'Engallu' (*Pellona* sp.)[37] ...	Andhra	21·8	75·7
Pomfret or 'Chanduva' (*Stromateus* sp.)[37] ...	,,	19·1	78·5
Pomfret, black or 'Halwa' (*Stromateus niger*)[36] ...	Bombay	18·4	70·6
Pomfret, black or 'Halwa' (*Parastromateus niger*)[35] ...	,,	19·4	...
Pomfret, black or 'Halwa'[32] ...	West Pakistan	18·4	70·6
Pomfret, black or 'Karuppu avoli'[34]	Kerala	20·3	74·5
Pomfret, white (*Stromateus cinereus*)[35]	Bombay	17·5	...
Pomfret, white or 'Saranga'[36] ...	,,	16·7	71·0
Pomfret, white or 'Vellai avoli'[34] ...	Kerala	17·0	78·4
'Rangoli'[38] ...	Bombay	16·9	66·6
Ray or 'Neithirandi' (*Rhinoptera seweli*)[34] ...	Kerala	20·9	75·3
Redfish (*Sebastes norvegicus*)[16] ...	Britain	18·1–18·5	...
Ribbon fish or 'Savallu' (*Trichiurus haumela*)[37] ...	Andhra	19·1	79·3
Ribbon fish or 'Vallithalayan' (*Trichiurus savala*)[34] ...	Kerala	18·1	76·6
Ribbon fish or 'Wakti'[36] ...	Bombay	22·0	74·7
Saithe (*Gades virens*)[16] ...	Britain	16·4–20·3	81·2
Salmon, Indian or 'Dara' (*Polynemus indicus*)[36] ...	Bombay	15·5	77·4
Salmon, Indian or 'Dharo'[35] ...	,,	20·6	...
Salmon, Indian or 'Rawas' (*Polynemus tetradactylus*)[36] ...	,,	16·5	76·0
Salmon, Indian or 'Rawas'[32] ...	West Pakistan	16·5	76·0
Salmon, Indian or 'Rawas' (*Elautheroma tetradactylus*)[35] ...	Bombay	19·7	...
Sardine or 'Ambatta' (*Opisthopterus tartoor*)[34] ...	Kerala	18·2	78·3
Sardine or 'Chala mathi' (*Sardinella fimbriata*)[34] ...	,,	20·8	77·2
Sardine or 'Kavallu'[37] ...	Andhra	21·0	78·1
Sardine or 'Tarli' (*Clupea fimbriata*)[36]	Bombay	18·6	77·4
Seer fish or 'Aya kora' (*Cybium guttatum*)[34] ...	Kerala	22·5	72·7
Seer fish or 'Surmai' (*Cybium commersonii*)[36] ...	Bombay	17·9	78·9
Seer fish or 'Surmai'[32] ...	West Pakistan	17·9	78·8

TABLE XIX. *Protein Content of Fish and Fish Products*

NAME	Locality	Protein Content: N × 6·25 %	Moisture Content %
Seer fish or 'Surmai' (*Cybium kuhlii*)[38]	Bombay	19·9	63·0
Seer fish or 'Surmai' (*Scomberomorus guttatum*)[35] ...	Bombay	19.7	...
Seer fish or 'Vanjaram' (*Scomberomorus* sp.)[37] ...	Andhra	22·4	74.9
Shad, Indian or 'Bhing' (*Clupea toli*)[36]	Bombay	18·0	78·3
Shad, Indian or 'Palla' (*Hilsa ilisha*)[36]	,,	21.5	71·5
Shark or 'Mushi' (*Carcharinus limbatus*)[36] ...	Bombay	26·1	72·0
Shark or 'Sravu' (*Carcharius lacticaudus*)[34] ...	Kerala	22·9	75·5
Shark or 'Sravu' (*Carcharius menisorrah*)[34] ...	Kerala	21·6	76·0
Shark or 'Sorra'[37] ...	Andhra	21·9	72·8
Silver bar fish or 'Karli' (*Chirocentrus dorab*)[36] ...	Bombay	19·8	76·1
Silver belly fish or 'Chakra mullan' (*Leiognathus insidiatrix*)[34] ...	Kerala	19·2	76·4
Silver belly fish or 'Nalla mullan' (*Leiognathus bindus*)[34] ...	,,	18·8	76·0
Silver bellies or 'Karalu' (*Leiognathus* sp.)[37] ...	Andhra	22·5	77·4
Sole or 'Vala manthal' (*Cynoglossus semifasciatus*)[34] ...	Kerala	19·5	72·4
Sole (*Solea vulgaris*)[16] ...	Britain	18·8	77·9
'Sooga machli' (*Eutropiichthys vacha*)[10] ...	Bihar	20·8	75·8
Sword fish (*Xiphias gladius*)[41] ...	United States	18·7	76·6
Threadfin or 'Bahmeen' (*Polynemus heptadactylus*)[34] ...	Kerala	17·9	76·6
Torsk (*Brosmius brosme*)[16] ...	Britain	18·4	...
Tunny or 'Sooda' (*Thynnus macropterus*)[34] ...	Kerala	23·8	71·9
Turbot (*Rhombus maximus*)[16] ...	Britain	16·8–20·6	78·3
Whiting (*Gadus merlangus*)[16] ...	Britain	16·4–19.0	80·4
Whiting, Indian or 'Poozhan' (*Sillago sihima*)[34] ...	Kerala	19.2	77·1
White bait or 'Nethal' (*Stolephorus tri*)[34]	,,	14·5	79·1
Witch (*Pleuronectes cynoglossus*)[16] ...	Britain	14·6–17·5	81·0
Shellfish and Crustacea			
Blue mussel or 'Kaduka' (*Mytilus edulis*)[34] ...	Kerala	9·9	81·5
Chank, Indian (*Xancus pyrum*)[42] ...	Madras	24.8	67·5
Clam, edible, average of 29 samples (*Meretrix casta*)[43] ...	Madras	9·8	77·8
Crab (*Cancer pagurus*)[16] ...	Britain	22·4	73·6
Crab or 'Khekda' (*Scylla serrata*)[36] ...	Bombay	15·8	81·0
Crab or 'Khekla'[32] ...	West Pakistan	15·8	81·0
Crab or 'Kekra'[44] ...	Bihar	11·9	61·7
Lobster (*Homarus vulgaris*)[16] ...	Britain	19·7–20·7	71·5–75·0
Lobster or 'Shevandi' (*Panulirus ornatus*)[36] ...	Bombay	19·6	76·3

TABLE XIX. *Protein Content of Fish and Fish Products*

NAME	Locality	Protein Content: N × 6·25 %	Moisture Content %
Lobster or 'Shavandi'[32] ...	West Pakistan	19·6	76·3
Lobster or 'Tengul gorla' (*Paloemon* sp.)[44] ...	Bihar	20·5	77·3
Oyster, edible, average of 29 samples (*Ostrea virginiana*)[43] ...	Madras	9·8	80·0
Prawn (*Leander serratus*)[16] ...	Britain	22·8	71·2
Prawn (*Peneus menoder*)[35] ...	Bombay	19·4	...
Prawn or 'Andail gorla' (*Paloemon* sp.)[44] ...	Bihar	21·5	75·5
Prawn or 'Chemmin' (*Peneus monodon*)[34] ...	Kerala	17·6	78·5
Prawn or 'Chemmin' (*Peneus Semisulcatus*)[34] ...	Kerala	20·8	76·7
Prawn or 'Jheenga'[32] ...	West Pakistan	18·8	73·0
Prawn or 'Karuana gorla' (*Paloeman lamarrei*)[44] ...	Bihar	17·5	76·6
Prawn or 'Kolambi' (*Parapeneopsis sculptilus*)[36] ...	Bombay	16·2	75·0
Prawn or 'Kozhi chemmin' (*Peneopsis dobsonii*)[34] ...	Kerala	18·0	78·9
Prawn or 'Vala chemmin' (*Trachypeneus asper*)[34] ...	Kerala	18·7	78·6
Shrimp (*Crangon vulgaris*)[16] ...	Britain	22·0–23·2	67·6–70·0
Shrimp or 'Bhat jhinga,' immature (*Paloemon* sp.)[40] ...	...	14·8	75·5
Shrimp or 'Karandi' (*Leander styliferus*)[36] ...	Bombay	18·3	77·6
Shrimp or 'Khrandi'[32] ...	West Pakistan	18·3	77·6
Fish Products			
'Bali kanakda,' dried[45] ...	Bengal	44·0	17·5
Chank, Indian, dried chips[42] ...	Madras	70·0	13·0
'Chiki,' dried[45] ...	Bengal	54·7	14·6
'Ghogra,' dried[46] ...	Bombay	56·0	...
'Goga chingri,' dried[45] ...	Bengal	55·4	15·0
'Halda chingri,' dried[45] ...	Bengal	56·0	16·0
'Joyali magur,' dried[45] ...	Bengal	69·7	13·6
'Kanas,' dried (*Labeo calabasu*)[46] ...	Bombay	68·4	...
'Kankut,' dried[46] ...	,,	60·2	...
'Kirid,' dried (*Bagarius yarreli*)[46] ...	,,	59·9	...
'Maral,' dried (*Ophiocephalus leucopunctatus*)[46] ...	Bombay	62·0	...
'Modal machh,' dried[45] ...	Bengal	56·2	15·5
'Pata machh,' dried[45] ...	Bengal	64·6	12·6
'Rangi chingri,' dried[45] ...	Bengal	56·3	17·8
'Rupapatar,' dried[45] ...	Bengal	54·6	14·2

TABLE XIX. *Protein Content of Fish and Fish Products*

NAME	Locality	Protein Content: N × 6·25 %	Moisture Content %
'Sada chingri,' dried[45] ...	Bengal	50·8	16·4
'Shanka chur,' dried[45] ...	,,	67·2	16·4
'Shivada,' dried (*Wallagonia attu*)[46] ...	Bombay	55·1	...
'Sukhuva chelwa,' dried (*Chela phulo*)[29] ...	Bihar	64·8	4·7
'Sukhua jhinga,' dried (*Paloemon lamarrei*)[29] ...	Bihar	68·1	6·0
'Sukhua machli,' dried (*Amblypharyngodon* sp.)[29] ...	Bihar	60·0	2·6
'Sukhua machli,' dried (*Barbus ticto*)[29]	,,	56·0	2·5
'Sukhua machli,' dried (*Clupea chapra*)[29] ...	Bihar	68·9	3·8
'Sword fish,' dehydrated[41] ...	United States	68·1	2·4
'Taltapra,' dried[45] ...	Bengal	54·5	11·0
'Tangra,' dried[45] ...	,,	54·9	13·8
'Tapra' dried[45] ...	,,	62·3	12·6
'Tapsi,' dried[45] ...	,,	58·5	16·2
'Vanz,' dried (*Cirrhina reba*)[46] ...	Bombay	70·0	...
Bombay duck or 'Bombil,' salted and dried[38] ...	Bombay	57·2	38·5
Bombay duck, salted and dried[48]* ...	Bengal	52·3	19·2
Bombay duck, salted and dried[48]† ...	,,	73·0	13·6
'Goda chingri', salted and dried[48]* ...	Bengal	59·0	15·1
'Goda chingri', salted and dried[48]† ...	,,	76·6	9·2
'Golim', salted and dried (*Acetes* sp.)[38]	Bombay	66·1	15·6
'Halda chingri,' salted and dried[48]* ...	Bengal	57·0	16·0
'Halda chingri,' salted and dried[48]† ...	,,	80·0	10·2
'Halwa,' salted and dried[38] ...	Bombay	27·8	49·0
'Khoira,' salted and dried[48]* ...	Bengal	47·6	20·3
'Khoira,' salted and dried[48]† ...	,,	70·2	14·3
Mackerel or 'Bangda,' salted and dried[38] ...	Bombay	46·6	34·5
'Makta chingri,' salted and dried[48]* ...	Bengal	49·2	19·1
'Makta chingri,' salted and dried[48]† ...	,,	73·4	11·3
'Mandeli,' small variety, salted and dried[38] ...	Bombay	52·5	31·1
'Modki,' salted and dried (*Penoeus* sp.)[38] ...	Bombay	72·9	4·2
'Mudal mach,' salted and dried[48]* ...	Bengal	49·8	26·3
'Mudal mach,' salted and dried[48]† ...	,,	76·2	12·6
'Mushi,' salted and dried (*Scoliodon sorrakewah*)[38] ...	Bombay	67·0	9·6
'Rangi chingri,' salted and dried[48]* ...	Bengal	56·3	18·6
'Rangi chingri,' salted and dried[48]† ...	,,	72·8	11·6
Ribbon fish or 'Vakati,' salted and dried[38] ...	Bombay	76·1	6·7

* dried on the beach by indigenous methods.

† dried in the factory by controlled methods.

TABLE XIX. *Protein Content of Fish and Fish Products*

NAME	Locality	Protein Content: N × 6·25 %	Moisture Content %
Ribbon fish, salted and dried[48]* ...	Bengal	58·8	17·8
Ribbon fish, salted and dried[48]† ...	,,	75·5	11·0
'Sada chingri,' salted and dried[48]* ...	Bengal	53·3	20·0
'Sada chingri,' salted and dried[48]† ...	,,	71·9	12·6
'Shengti,' salted and dried (*Macrones gluilo*)[38] ...	Bombay	37·1	47·2
'Sode,' var. I, salted and dried (*Parapeneus* sp.)[38] ...	Bombay	56·6	31·8
'Sode,' var. II, salted and dried[38] ...	,,	75·6	17·0
'Surmai,' salted and dried[38] ...	,,	38·6	43·3
'Tendli,' salted and dried (*Metapeneus* sp.)[38] ...	Bombay	60·8	17·8
Fish meal, fresh[49] ...	...	39·4–42·7	8·1–8·4
Fish meal, stored for 4½ months in gunny bags[49] ...	...	27·0	19·0
Fish meal, stored for 4½ months in glass container[49] ...	...	36·9	13·6
'Air' meal[50] ...	Bengal	77·9	4·9
Anchoveta meal[51] ...	Peru	62·6	...
Anchovies meal[52] ...	Orissa	62·7	8·5
Bonito meal[51] ...	Peru	59·5	...
Blue mussel meal (*Mytilis viridis*)[53] ...	Kerala	65·8	12·5
Chank meal (*Turbinelia pyrum*)[53] ...	Kerala	79·0	16·0
Clam meal (*Meretrix* sp.)[53] ...	,,	65·9	9·7
Dolphin fish meal[52] ...	Orissa	69·7	4·3
Herring meal, low temp. dried[54] ...	United States	70·4	...
Herring meal, commercial, flame dried[54]	,,	72·0	...
'Katla' meal[50] ...	Bengal	73·5	7·2
'Koi' meal[50] ...	,,	61·8	3·2
'Koral' meal[50] ...	,,	93·0	3·1
Machete meal[51] ...	Peru	57·3	...
Mackerel meal, ungutted[52] ...	Orissa	60·1	8·7
Mackerel meal, gutted[52] ...	,,	68·1	8·7
Mackerel meal[53] ...	Kerala	73·4–76·7	7·8–12·8
Mackerel meal, cooked and pressed[53]	,,	74·6	3·7
'Mrigal' meal[50] ...	Bengal	78·4	7·5
Mussel meal[1] ...	...	11·6	2·1
Oil Sardine meal[52] ...	Orissa	65·3	9·7
Oil Sardine meal[53] ...	Kerala	69·8	8·7
'Poa' meal[50] ...	Bengal	75·4	5·8
Prawn meal, whole, cooked and pressed[53] ...	Kerala	85·8	10·5

* dried on the beach by indigenous methods.

† dried in the factory by controlled methods.

TABLE XIX. *Protein Content of Fish and Fish Products*

NAME		Locality	Protein Content: N × 6·25 %	Moisture Content %
Prawn meal, whole, beach dried[53]	...	Kerala	64·4	3·5
Prawn shell meal[53]	...	,,	55·9	6·2
Ribbon fish meal[53]	...	Kerala	81·8	12·6
Salmon meal[55]	...	United States	57·7	...
Sardine meal, whole[53]	...	Kerala	50·6	5·1
Sardine meal, heads[53]	...	,,	53·6	10·4
'Sarputi' meal[50]	...	Bengal	70·7	5·8
Shark meal[52]	...	Orissa	77·8	9·9
Shark meal, average of 19 samples[56]	...	United States	78·1	9·2
Shark head meal[53]	...	Kerala	84·0	11·5
Shark liver meal[53]	...	,,	36·4	8·0
'Singhi' meal[50]	...	Bengal	81·4	6·9
Skate fish meal[52]	...	Orissa	77·9	6·5
Sole fish meal[52]	...	Orissa	61·4	6·1
Sole fish meal or 'Manthal' meal, cooked and pressed[53]	...	Kerala	80·7	6·4
Sole fish meal or 'Manthal' meal, beach dried[53]	...	,,	60·6	5·0
Star fish meal (*Pentaceras* sp.)[53]	...	,,	7·8	3·5
Whale meal (*Cetacea* sp.)[51]	...	Peru	77·0	...
Whale meat meal, grade A[57]		South Africa, Australia and	80·1-86·5	7·4-9·4
Whale meat meal, grade B[57]	...	Br.tish floating factories in	56·9	6·6
Whale meat meal, grade C[57]		Antartic sea	18·7	3·6
White bait meal (*Stol ephoroustoi*)[55]	...	Kerala	73·8	12·0
White fish flour[58]	...	South Africa	89·0	4·0
Eel liver, silver,[39]	...	Britain	13·2	77·9
Eel liver, yellow[39]	...	,,	14·3	78·7
Whale (Sei), heart[61]	...	Japan	17·2	72·3
Whale (Sei). kidney[61]	...	,,	16·1	79·8
Whale (Sei), liver[61]	...	,,	21·6	73·1
Whale (Sei), lung[61]	...	,,	20·0	76·7
Whale (Sei), pancreas[61]	...	,,	17·9	75·5
Whale (Sei), tongue[61]	...	,,	7·5	41·1
Fish paste or 'Ngapi seinsa'[62]	...	Burma	15·9	...
Bloater paste[63]	...	England	16.2	69·0
Salmon and anchovy paste[63]	...	,,	16·4	67·3
Salmon and shrimp paste[63]	...	,,	14·1	67·8
Fish sauce, grade I[64]	...	Thailand	13·1	...
Fish sauce, grade II[64]	...	,,	8·4	...
Fish sauce, grade III[64]	...	,,	2·8	...
Fish sauce, grade IV[64]	...	,,	0·9	...
Fish sauce or 'Nuoc-mam,' first quality[65]	...	Viet Nam	13·8	...
Fish sauce or 'Nuoc-mam,' ordinary quality[65]	...	,,	6·9	...
Fish sauce or 'Nuoc-mam'[66]	...	,,	14·4	...

TABLE XX

NUTRITIVE VALUE OF FISH PROTEINS

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Nutritive Value: Coefficient of true digestibility %	Nutritive Value: Protein efficiency ratio
Fresh water fish					
'Air' (*Arius arius*)[50] ...	20.5	10 15	74.5 ...	94.3 ...	... 1.7
Carp, common (*Cyprinus carpio*)[117] ...	...	...	...	...	1.8
Carp, golden (*Carassius auratus*)[117] ...	...	...	...	...	1.4
'Katla' (*Catla catla*)[50] ...	19.2	10 15	78.0 ...	86.5 ...	... 1.8
'Koi' (*Anabus testudineus*)[50]	14.6	10	86.8	95.6	...
'Koral' [50]	21.0	10	83.3	97.1	...
Loaches (*Misgurnus anguillicaudatus*)[109] ...	...	...	84.0	84.0	...
'Mrigel' (*Cirrhina mrigala*)[50]	19.6	10 15	72.1 ...	92.4 ...	... 1.7
'Poa'[50] ...	18.6	10	75.8	95.9	...
'Sarputi' (*Barbus sarana*)[50] ...	17.5	10	82.4	96.3	...
'Singhi' (*Saccobranchus fossilis*)[50] ...	16.0	10 15	88.5 ...	95.5 ...	... 1.5
Snake head (*Ophiocephalus argus*)[117] ...	...	...	...	...	2.0
Whitefish (*Cultes brevicauda*)[109] ...	...	...	83.0	96.0	...
Marine fish					
Jew fish or 'Ghol' (*Scioenea* sp.)[107]	18.4	5 10 15	81.5 71.3 58.8	83.0 83.4 76.2	... ...
Salmon, Indian or 'Ravas' (*Polynemus* sp.)[107]	20.6	5 10 15	79.5 68.0 52.2	85.0 85.2 67.5	... ...
Seer fish or 'Surmai' (*Cybium* sp.)[107]	19.9	5 10 15	75.6 68.0 59.4	85.9 81.2 76.1	... ...
Shark or 'Mushi' (*Scoliodon* sp.)[107]	14.9	5 10 15	72.9 62.1 53.3	82.2 84.2 70.8	... ...

Table XX. *Nutritive Value of Fish Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value		
			Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Shellfish and Crustacea					
Cuttlefish (*Sepia esculenta*)[108] ...	...	12	61.0	85.0	...
Prawn or 'Golim' (*Acetes* sp.)[107]	...	5 10 15	75.6 60.7 54.5	83.7 86.0 71.9	... ...
Prawn or 'Sode' (*Parapeneus* sp.) sample I[107]	21.4	5 10 15	76.0 66.5 58.8	84.2 85.5 72.6	... ...
Prawn or 'Sode,' sample II[107]	...	5 10 15	78.2 74.9 60.8	85.7 87.1 73.2	... ...
Prawn or 'Tendli' (*Metapeneus* sp.)[107]	19.6	5 10 15	71.8 65.7 59.6	86.4 85.8 73.2	... ...
Sagittated calamary (*Omwastrephus pacificus*)[108] ...	...	...	91.0	92.0	...
Shrimp (*Macrobracium nipponensis*)[109] ...	...	...	77.0	96.0	...
Trepang (*Stichopus japonicus*)[108] ...	...	...	75.0	91.0	...
Fish protein					
Cod protein, extracted (*Gadus morrhua*)[125] ...	...	...	87.0*	...	...
Cod protein, extracted, heated at 45°C for 48 hrs.[125] ...	...	...	80.0*	...	...
Cod protein, extracted, heated at 100°C for 48 hrs.[125] ...	...	...	49.0*	...	...
Herring protein, extracted (*Clupea harengus*)[125] ...	...	...	76.0*	...	...
Mackerel protein, extracted (*Scombar scombris*)[118] ...	...	9	...	...	2.1
Sword fish protein, extracted (*Xiphias gladius*)[81] ...	68.1	8	...	...	3.2
Tuna protein, extracted (*Thunnus* sp.)[118] ...	...	12	...	...	2.1

* denotes Net Protein Utilisation (Biological value × Coefficient of true digestibility.)

TABLE XX. *Nutritive Value of Fish Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Nutritive Value: Coefficient of true digestibility %	Nutritive Value: Protein efficiency ratio
Fish products					
Fish, dried[116] ...	82·5	8	...	...	3·5
Fish meal from lean fish, commercial[127] ...	59·0-72·5	...	61·0-78·0	88·0-97·0	...
Fish meal from lean fish, defatted and deodourised[127] ...	64·7-75·2	...	53·0-82·0	93·0-96·0	...
Fish meal from semi-lean fish, defatted and deodourised[127] ...	74·7-79·4	...	39·0-71·0	47·0-96·0	...
Fish meal from fatty (oily) fish[125] ...	...	...	32·0-36·0*	...	...
Fish meal from fatty fish, defatted and deodourised[127] ...	66·6-73·4	...	36·0-59·0	68·0-81·0	...
Fish meal (from heads and inedible fish)[112] ...	...	8	71·0	...	...
Fish meal (fertilizer grade)[125] ...	...	...	36·0*	...	...
Anchovies meal (*Engraulis encrasicholus*)[111] ...	50·3	8	82·6	76·6	...
Cod meal, vacuum-dried in the laboratory[125] ...	...	...	84·0*	...	...
Cod meal, dried at 50°C in the laboratory[125] ...	...	...	82·0*	...	...
Cod meal, dried at 100°C in the laboratory[125] ...	...	...	70·0*	...	...
Cod meal, commercial[127]	68·6	...	66·0	94·0	...
Cod meal, extracted[127] ...	77·5	...	77·0	92·0	...
Cod meal, extracted and deodourised[127] ...	76·9	...	76·0	92·0	...
Cod meal, defatted and deodourised[127] ...	74·0	...	69·0	95·0	...
Cod fillet meal, defatted and deodourised[127] ...	89·1	...	67·0	95·0	...
Crab meal (*Cancer pagurus*)[111] ...	35·0	8	85·9	70·7	...
Crayfish meal (*Astacus fluviatilis*)[112] ...	...	8	81·0	...	...
Dogfish meal (*Squalus acanthias*)[125] ...	...	...	50·0*	...	...
Dogfish meal, commercial[248] ...	...	...	51·0*	...	...
Haddock meal, vacuum-dried (*Melanogrammus aeglefinus*)[114] ...	64·0	10	85·0	...	...
Haddock meal, flame-dried[114] ...	61·8	10	78·0	...	...
Herring meal, Alaska[111] ...	69·7	8	79·7	87·2	...
Herring meal with solubles[111] ...	52·1	8	82·2	89·6	...

* denotes Net Protein Utilisation (Biological value × Coefficient of true digestibility.)

TABLE XX. *Nutritive Value of Fish Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Coefficient of true digestibility %	Protein efficiency ratio
Herring meal, commercial[127] ...	70.0	...	68.0	94.0	...
Herring meal, defatted[127]	84.2	...	59.0	96.0	...
Herring meal, defatted and deodourised[127] ...	83.0-87.0	...	60.0-79.0	93.0-94.0	...
'Hilsa' meal, sun dried (*Clupea ilisa*)[33] ...	64.3	10	73.5	89.1	1.7
'Hilsa' meal, steam dried[33] ...	60.0	5	78.0	82.5	0.3
		10	69.5	82.6	1.3
		15	62.1	81.3	1.5
Menhaden meal (*Brevoortia tyrannus*)[111]	63.4	8	86.9	89.2	...
Menhaden meal, vacuum-dried[114] ...	53.2	10	76.0	...	...
Menhaden meal, flame-dried[114] ...	51.1	10	70.0	...	...
Red fish meal[111] ...	57.1	8	87.3	86.8	...
'Ruhee' meal, sun dried (*Labeo rohita*)[33] ...	76.6	10	86.6	96.5	1.8
'Ruhee' meal, steam dried[33]	72.2	5	82.3	92.0	1.5
		10	78.9	88.6	1.6
		15	72.5	90.0	1.7
Sardine meal (*Sardinella fimbriata*)[111] ...	58.4	8	86.4	97.8	...
Sardine meal, commercial[127] ...	63.8	...	77.0	87.0	...
Sardine meal, defatted and deodourised[127] ...	81.8	...	70.0*	...	...
Whale meat meal (*Cetacea* sp.)[112] ...	...	8	67.0	...	...
Whale meat and bone meal[112] ...	...	8	67.0	...	...
Whale and fish meal[112] ...	...	8	63.0	...	...
Whitefish meal[125] ...	...	...	58.0-73.0*	...	...
Whitefish meal[112] ...	...	8	94.0	...	...
Whitefish meal[113] ...	...	10	84.0	...	...
Whitefish flour[110] ...	86.2; 89.4	7	96.7	95.6	...

* denotes Net Protein Utilisation (Biological value × Coefficient of true digestibility.)

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Fish[97] ...	...	5·6	1·9	6·8	4·0	1·3
Fish muscle[70] ...	...	7·4	2·6	9·0	3·8	1·2
Fish muscle[71] ...	...	5·8	2·5	8·6	...	1·1
Fish muscle[89] ...	97·5	6·4	2·1	8·7	4·3	1·2
Fresh water fish						
Carp heads (*Thynnicthys* sp.)[11] ...	...	5·5	0·6	4·2	...	...
Salmon, raw (*Oncorhynchus tschawytscha*)[74, 75] ...	19·8	5·7	2·6	8·1	...	0·9
Salmon, heat-processed[74, 75]	19·3	5·7	2·5	8·1	...	0·9
Salmon, muscle, steak[89, 93] ...	23·7	6·4	2·3	9·0	4·4	1·4
Marine fish						
Cat fish or 'Shingala' (*Arius caelatus*)[104] ...	...	0·7	...	1·2	...	...
Cat fish or 'Shingala' (*Osteogeniosus militaris*)[104]	...	0·6	...	0·7	...	...
Cod muscle, steak (*Gadus morrhua*)[89, 93] ...	23·1	6·3	2·0	8·4	4·5	1·3
Cod, red[83] ...	9·0	4·3	1·6	14·4	0·4	0·1
'Dhoma' (*Sciaena bleekeri*)[104]	...	0·6	...	1·2	...	...
'Dhoma' (*Sciaenoides brunnesus*)[104] ...	...	0·7	...	0·7	...	...
Haddock (*Melanogrammus aeglefinus*)[87] ...	...	5·7	1·9	8·6	...	0.9
Haddock, boneless, fresh[73]	19·6	9·2	3·3	9·6	...	1·2
Haddock fillet, average of 3 samples[95] ...	...	5·5	2·0	9·9	...	1·1
Halibut, large steak (*Hippoglossus hippoglossus*)[73] ...	20·0	8·4	3·7	9·4	...	1·1
Herring (*Clupea harengus*)[83]	9·1	5·9	2·0	8·2	2·2	0·7
Horse mackerel (*Caranx rottleri*)[11]	...	4·5	1·8	6·7	...	...
Mackerel, Atlantic, raw (*Scomber scombris*)[74, 75] ...	17·6	5·6	4·0	8·2	...	0·9
Mackerel, Atlantic, heat-processed[74, 75] ...	18·5	5·7	3·6	8·0	...	1·0
Mackerel, Pacific, raw (*Pneumatophorus diego*)[74,75]	21·2	5·5	5·5	8·8	...	1·0
Mackerel, Pacific, heat-processed[74, 75] ...	22·8	5·3	5·2	8·3	...	1·0
'Mandeli' (*Coilia dussumieri*)[104] ...	...	0·7	...	1·0	...	...
Mullet or 'Boi' (*Mugil olur*)[72]	18·1	6·6	1·9	...	1·6	0·4

* (C: Chemical; CC: Chromatographic;

ACIDS							Method of estimation*
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
4·5	1·2	3·4	4·4	...	...	...	MM
4·4	1·2	3·2	4·7	9·5	6·5	6·0	MM
3·9	...	2·9	3·4	8·8	5·8	6·7	M
4·5	1·2	3·7	4·2	...	...	...	C
...	...	...	...	...	...	...	C
3·7	...	3·0	4·2	7·1	5·0	5·5	M
3·7	...	3·1	4·5	7·4	4·9	5·6	M
4·5	1·0	3·5	4·2	...	...	...	C
...	...	0·5	...	...	...	...	CC
...	...	0·4	...	...	...	...	CC
4·3	1·1	3·5	4·5	...	...	...	C
4·4	...	2·6	5·1	11·4	6·8	5·0	...
...	...	0·6	...	...	...	...	CC
...	...	0·5	...	...	...	...	CC
3·7	...	2·8	4·2	7·5	5·4	5·6	M
4·1	...	4·1	4·0	8·6	6·2	5·9	MM
3·8	1·0	2·9	4·5	7·9	...	6·3	M
3·4	...	4·5	...	8·8	6·2	6·0	MM
4·5	...	2·2	4·5	8·0	6·4	5·1	...
...	...	...	...	...	...	...	C
3·5	...	2·7	4·7	7·0	5·3	5·6	M
3·4	...	2·8	4·9	7·3	4·9	5·2	M
3·9	...	2·8	4·4	7·6	5·3	5·4	M
3·8	...	2·8	4·4	7·4	4·8	5·2	M
...	...	0·5	...	...	...	...	CC
4·2	0·5	4·4	7·1	11·3	5·9	5·5	M

M: Microbiological; MM: Miscellaneous).

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
'Niv' (*Chaetoessus nasus*)[104]	...	0·6	...	0·9	...	...
'Pakat' (*Dasyatis zugei*)[72] ...	21·5	5·2	1·7	19·5	1·4	0·6
Pomfret (*Stromateus* sp.)[72] ...	18.5	6·1	1·8	...	1·3	0·6
Pomfret[87] ...	...	5·4	1·9	10·8	...	0·9
Pomfret, black or 'Halwa' (*Parastromateus niger*)[72] ...	21·6	3·7	1·3	...	1·3	0·7
Salmon, Indian or 'Rawas' (*Polynemus tetradactylus*)[72] ...	19.4	7·4	1·7	19·8	1·6	1·0
Sandart (*Lucioperca sandra*)[249] ...	...	...	...	...	4·7	2·2
Sardine, raw (*Sardinops caerulea*)[74, 75] ...	20·8	4·9	5·0	8·3	...	1·1
Shad (*Ethmydium chilcae*)[87]	...	5·7	2·3	9·8	...	1·1
Shad[99] ...	...	...	...	...	...	...
Shad, Indian or 'Bhing' (*Hilsa toli*)[104] ...	...	0.7	...	0.9	...	...
Shad, Indian or 'Pala' (*Hilsa ilisha*)[104] ...	...	0·7	...	1.0	...	...
Shark (*Mustelus mento*)[99] ...	...	...	...	...	...	...
Shark meat[79] ...	...	5·7	2·2	7·4	3·1	0·9
Shark or 'Mushi' (*Carcharius limbatus*)[72] ...	20·5	5·2	1·7	16·5	1·5	0·8
Sword fish, broiled (*Xiphius gladius*)[81]	28·7	8·8	2·9	7·1	...	1·5
Threadfin (*Polynemus* sp.)[11]	...	5·0	2·4	5·0	...	...
Tunny (*Thunnus macropterus*)[99]	...	...	...	...	...	...
Whale meat (*Cetacea* sp.)[239]	...	6·5	3·6	0·5	2·4	trace
Shellfish and Crustacea						
Crustacean muscle[79] ...	...	7·6	1·9	8·3	4·7	1·2
Crustacean muscle[89] ...	...	6·5	1·8	8·4	4·8	1·2
Lobster (*Panulirus ornatus*)[72]	21·3	7·2	1·2	17·6	0·8	0·2
Prawn (*Peneus* sp.)[72] ...	20.1	8·3	1·6	18·5	1.0	0.4
Shrimp (*Crangon vulgaris*)[89, 93] ...	23·1	6·6	1·8	8·3	4·7	1·2
Shrimp, heat-processed[74, 75]	23·3	9·4	2·2	8·5	...	1·0
Fish protein						
Cod muscle protein[94] ...	93·8	11·3	2·0	11·6	1·9	0·8
Herring protein[101] ...	83·6	...	...	8·9	...	...
'Hilsa' globulin (*Clupea ilisa*)[214]	...	7·0	3·0	5·8	9·5	1·7
'Hilsa' glutelin[214] ...	...	9·1	2·2	4·6	7·5	1·6
'Ruhee' globulin (*Labeo rohita*)[214] ...	...	8·2	3·1	3·6	8·5	1·8

ACIDS							Method of Estimation
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
...	...	0·5	...	...	...	...	CC
2·7	1·0	1·6	4·6	12·5	5·2	3·5	M
3·5	1·3	3·0	6·9	10·7	5·2	5·0	M
3·2	...	2·6	4·4	7·3	5·0	4·0	M
2·1	trace	1·8	4·1	6·2	3·4	2·9	M
4·5	2·3	3·7	8·1	8·8	7·3	6·5	M
...	1·5	...	...	...	...	...	...
3·5	...	2·6	4·0	6·2	4·3	4·9	M
3·7	...	2·8	4·1	7·7	5·0	6·2	M
...	1·9	3·9	...	...	...	...	...
...	...	0·4	...	...	...	...	CC
...	...	0·5	...	...	...	...	CC
...	1·8	3·6	...	...	...	...	...
4·4	0·8	3·2	3·4	6·4	5·2	4·3	MM
3·7	0·9	2·0	5·4	7·9	5·4	4·3	M
4·1	...	2·9	2·6	8·0	7·7	3·2	M
...	...	...	...	...	...	...	C
...	1·9	3·7	...	...	...	...	...
...	...	...	...	3·5	...	6·3	...
4·8	1·3	3·4	4·0	...	...	...	MM
4·7	1.1	3·4	3·9	...	...	...	C
2·7	1·5	2·2	5·3	11·3	4·3	2·9	M
4·6	1·4	4·6	4·6	14·3	5·6	4·1	M
4·8	1·1	3·2	4·0	...	...	...	C
4·5	...	3·4	4·1	8·5	5·3	5·1	M
...	0·9	...	...	...	...	...	...
...	0·8	3·1	...	...	...	...	MM
...	0·7	...	...	...	...	...	C
...	1·7	...	...	...	...	...	C
...	1·4	...	...	...	...	...	C

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Trypto-phan %
'Ruhee' glutelin[214] ...	...	10·2	2·3	4·5	9·1	2·0
Waste fish protein[212] ...	...	2·5	2·5	1·0	3·0	...
Fish products						
Sword fish, frozen[81] ...	18·7	9·1	3·3	7·2	...	1·3
Haddock, debydrated[87] ...	...	5·3	1·7	9·2	...	0·9
'Kanas', dried (*Labeo calabasu*)[92] ...	68·4	5·6	1·6	7·6	...	...
'Kankut', dried[92] ...	60·2	6·4	2·8	10·6	...	...
'Karwa', dried (*Lethrinus karwa*)[103] ...	80·8	11·6-12·1	2·1	6·9	3·1	0·5
'Maral', dried (*Ophiocephalus leucopunctatus*)[98] ...	62·0	6·4	13·4	6·8	...	...
Mullet, dried (*Mulloides* sp.)[103] ...	82·8	9·8-11·0	6·6	4·4	3·6	0·6
Salmon, Indian or 'Rawas', dried[103] ...	85·1	7·1-8·4	7·9	2·2	2·4	0·8
Shad, dehydrated[87] ...	...	5·7	2·2	9·5	...	0·9
'Shivada', dried (*Wallagonia attu*)[98] ...	55·1	5·0	11·3	3·7	...	...
Sword fish, dehydrated[81] ...	68·1	7·6	2·8	6·8	...	1·0
'Vanz', dried (*Cirrhina reba*)[92] ...	70·0	6·3	0·4	15·9	...	...
Haddock, canned[87] ...	...	5·2	1·5	8·1	...	1·1
Sardine, raw, in oil[74, 75] ...	21·1	5·5	2·5	7·8	...	0·8
Sardine, raw, in tomato sauce[74, 75] ...	17·6	5·1	4·8	8·6	...	1·0
Sardine, precooked, in tomato sauce[74, 75] ...	19·3	5·4	4·9	9·5	...	1·1
Sardine, heat-processed, in oil[74, 75] ...	21·3	5·5	2·2	7·9	...	0·8
Sardine, heat-processed, in tomato sauce[74, 75] ...	18·9	5·0	4·5	8·1	...	1·0
Shad, canned[87] ...	...	5·2	1·9	9·0	...	0·8
Sword fish, canned[81] ...	17·5	9·6	2·9	7·0	...	1·1
Tuna, raw, in oil (*Thunnus* sp.)[74, 75] ...	25·8	5·4	5·7	8·2	...	1·1
Tuna, precooked, in oil[74, 75] ...	26·6	5·2	5·6	8·4	...	1·0
Tuna, heat-processed, in oil[74, 75]	25·6	5·2	5·9	8·3	...	0·9
Fish flakes, raw[74, 75]	24·4	6·0	2·0	9·0	...	1·0

ACIDS							Method of estimation
Phenyl-alanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
...	2·0	...	...	...	...	...	C
...	0.5	...	...	...	...	1·5	...
4·1	...	3·8	2·6	7·8	7·5	4·7	M
3·2	...	2·6	4·2	7·4	5·1	5·2	M
...	5·3	3·4	...	...	...	...	C
...	6·3	3·8	...	...	...	...	C
...	1·3	...	...	...	...	...	C
...	6·2	8·4	...	...	...	...	C
...	2·1	...	...	...	...	...	C
...	2·0	...	...	...	...	...	C
3·4	...	2·7	4·2	7·6	5·2	5·8	M
...	7·1	8·9	...	...	...	...	C
4·0	...	2·7	2·2	7·2	6·7	3·3	M
...	6·1	2·4	...	...	...	...	C
3·7	...	3·1	4·4	7·6	5·2	5·1	M
3·3	...	2·7	4·3	6·9	4·8	5·0	M
3·9	...	2·7	4·4	7·4	4·8	5·2	M
4·0	...	3·0	4·9	8·0	4·9	5·6	M
3·6	...	2·7	4·5	7·2	4·7	5·1	M
3·7	...	2·8	4·2	7·2	4·5	5·2	M
3·8	...	3·0	4·1	7·5	4·6	6·7	M
4·5	...	3·0	2·1	7·9	7·8	3·9	M
3·4	...	2·8	4·7	6·9	4·4	5·0	M
3·5	...	2·8	4·6	7·2	4·8	5·2	M
3·7	...	2·8	4·3	7·3	4·9	5·3	M
3·8	...	3·0	5·0	8·0	5·5	5·3	M

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Fish flakes, heat-processed[74, 75] ...	23·9	6·2	2·1	8·8	...	1·0
Fish meal[84] ...	75·0	6·0	3·1	8·8	3·1	0·8
Fish meal[85] ...	69·2	4·7	1·5	4·1	...	0·7
Fish meal[250] ...	69·6	...	...	...	...	...
Fish meal, average of 10 samples[76] ...	...	8·1	2·6	9·5	2·5	0·8
Fish meal, mainly herring[86]	87·5	8·1	2·8	9·5	2·9	0·9
Crab meal (*Cancer pagurus*)[85]	35·0	2·0	0·5	1·6	...	0·4
Herring meal[101] ...	66·2	...	...	6·9	...	...
Herring meal[83] ...	6·8	...	0·6	4·4	3·2	1·0
Herring meal, mean for 3 samples[82] ...	77·5	8·1	2·4	8·1	1·5	1·0
Herring meal, commercial[77]	72·5	6·4	2·2	11·3	3·0	0·7
Herring meal, low temp. dried[77] ...	71·6	6 5	2·5	12·2	2·6	1·1
Herring meal, expeller-pressed and vacuum dried[78] ...	...	7·3	1·7	7·8	...	0·9
Herring meal, flame-dried at low temp. (185°F)[78] ...	...	6·8	1·7	7·9	...	1·0
Herring meal, flame-dried at high temp. (220°F)[78] ...	...	6·2	1·7	6·0	...	1·1
Menhaden meal (*Brevoortia tyrannus*)[111] ...	...	5·9	2·4	5·7	2·8	1·2
Salmon meal, chum[82] ...	69·4	8·4	2·8	12·2	3·0	1·0
Salmon meal, pink (mean for 2 samples)[82] ...	69·8	8·1	2·5	11·8	2·8	0·9
Salmon meal, pink and sockeye[82] ...	66·9	8·6	2·5	11·0	2·8	0·9
Salmon meal, pink and 'soles' (mean for 2 samples)[82] ...	69·1	7·6	2·8	11·9	2·9	0·9
Salmon meal, sockeye[82] ...	61·3	8·3	2·5	10·4	3·1	0·9
Sardine meal[79] ...	...	7·4	2·4	7·8	4·4	1·3
Whale meal powder[100] ...	...	12·4	1·3	...	3·5	1·1
Whitefish meal[101] ...	67·9	...	...	6·1	...	...
Cod liver, red, dried[82] ...	70·6	7·2	2·7	8·0	1·5	1·2
Fish solubles[105] ...	...	2·8	3·7	3·1	...	0·2
Fish solubles, dried[84] ...	69·4	3·7	7·2	3·3	0·7	0·4
Fish solubles, condensed (mean for 4 samples)[82] ...	31·3	3·5	1·1	4·5	0·6	1·9
Sardine solubles, condensed[251] ...	33·5	4·3	5·8	4·9	...	0·4
Whale solubles, condensed[251]	47·5	6·8	1·1	4·0	...	0·5
Stickwater[79] ...	...	5·4	2·6	4·7	0·8	1·1

ACIDS							
Phenyl-alanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	Method of Estimation
3.8	...	3.0	4.9	8.1	5.6	5.4	M
4.7	...	2.4	4.1	8.5	6.5	6.0	M
3.1	...	1.7	3.1	4.8	3.3	3.8	M
4.0	...	...	...	7.8	5.2	6.4	M
4.4	...	2.6	5.1	9.1	5.9	6.4	M
4.1	0.9	3.1	4.3	7.8	5.6	7.0	...
1.7	...	0.6	1.2	2.0	1.3	1.7	M
...	1.4	2.7	...	...	...	...	MM
4.4	...	2.7	4.4	10.1	6.6	5.7	...
4.4	...	2.8	5.2	8.9	6.7	5.9	...
3.6	...	2.3	3.6	7.4	4.6	5.2	M
4.0	...	3.0	3.8	7.3	4.9	5.2	M
3.8	...	2.5	4.1	7.4	4.9	5.4	M
3.8	...	2.5	4.0	7.5	4.7	5.2	M
3.7	...	2.6	3.7	7.4	4.7	5.2	M
4.8	1.0	3.0	5.0	10.0	4.0	4.0	MM
5.3	...	2.6	5.4	10.8	5.9	6.8	...
4.5	...	2.6	5.3	9.1	5.8	6.4	...
4.4	...	2.6	5.1	9.1	4.5	5.5	...
4.6	...	2.5	5.2	9.0	5.5	5.5	...
3.4	...	2.6	4.6	7.8	5.6	6.3	...
4.5	1.2	3.5	4.5	7.1	6.0	5.8	MM
6.3	...	3.3	4.0	...	...	...	...
...	1.4	2.9	...	...	...	...	MM
5.8	...	3.0	4.8	8.4	5.5	5.8	...
1.5	...	1.0	1.5	3.0	1.7	1.9	M
1.7	...	1.2	1.7	2.6	2.3	2.2	M
2.0	...	1.7	2.0	4.1	2.8	2.6	...
2.3	...	1.5	2.4	4.7	2.7	3.0	M
...	0.1	1.4	...	3.4	...	3.7	M
1.9	...	1.5	2.3	...	...	...	MM

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Stickwater[106] ...	...	3·7	0·5	4·1	4·1	1·3
Stickwater from herring[83] ...	6·0	3·7	0·5	4·1	4·1	1·3
Stickwater from herring (mean for 2 samples)[82] ...	5·4	5·9	1·4	6·2	0·4	0·2
Stickwater from Salmon, chum[82] ...	3·8	7·8	1·7	8·1	0·6	0·2
Stickwater from Salmon, pink (mean for 2 samples)[82] ...	4·3	8·0	1·6	7·0	0·7	0·3
Stickwater from Salmon, pink and sockeye[82] ...	4·3	7·7	1·6	6·8	0·7	0·3
Stickwater from Salmon, pink and 'soles' (mean for 2 samples)[82] ...	4·2	8·0	1·7	7·0	0·6	0·3
Glue water from mixed Balaena whale blubber, spray-dried[105] ...	91·9	7·9	0·9	2·6	...	0·2
Glue water from sperm whale blubber, spray-dried[105] ...	69·4	8·4	0·7	1·5	...	0·1
Glue water from humpback whale blubber, spray-dried[105] ...	...	5·6	0·5	2·4	...	0·3
Glue water from mixed Balaena whale meat, spray-dried[105] ...	87·5	7·2	2·3	2·0	...	0·4

ACIDS							Method of Estimation
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
1·8 1·8	... ...	0·6 0·7	2·2 2·2	3·9 3·9	1·6 1·6	2·1 2·1	M ...
2·2	...	1·8	2·6	4·2	2·2	2·6	...
2·1	...	1·9	2·9	3·7	2·2	2·7	...
2·1	...	2·1	3·1	3·5	2·0	2·6	...
2·2	...	2·0	2·9	3·3	2·3	2·5	...
2·2	...	1·9	2·9	3·9	2·4	2·5	...
1·9	...	0·3	2·4	3·3	2·2	2·8	MM
2·8	...	0·2	2·2	4·8	4·1	2·6	MM
2·2	...	0·2	2·3	3·9	3·5	2·9	MM
2·0	...	0·3	2·3	4·1	4·2	3·4	MM

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CHAPTER XI

LEAVES AND GRASSES

The proteins of green plants are concentrated by passage into seeds (cereals and legumes) or by transformation into milk or meat[1] and are thus rendered available for human consumption. The amount of protein (lbs/acre/annum) that could be derived from land varies with the crop; under grass it is 600, under beans, 370 and under wheat 269, but only 90 if the land is used for milk production and 54 if the land is used for meat production[1]. According to another estimate[2], the annual yield of leaf protein from an acre of land is of the order of 1250 lb. It has been reckoned that the conversion of herbage protein into palatable protein concentrates for use as human food can be more efficiently effected by chemical processing than through the ruminant[2].

Lucerne or Alfalfa

In order of importance among edible leaves, lucerne or alfalfa (*Medicago sativa*) comes first and has been the subject of several investigations. Escudero and Landabure have summarised results available up to 1943 on the nutritive principles in lucerne[3].

Protein content: Lucerne is a rich source of protein[4], varying in content from 16 per cent to 23 per cent on the dry weight basis[5, 6]. No consistent varietal or seasonal differences have been observed[5], but a definite decrease in protein content with maturity has been reported[5, 7].

Amino acid composition: Lucerne proteins are generally deficient in the sulphur-containing amino acids[6, 8-10], but are reported to be richer in cystine than grass proteins[8]. The cystine and methionine contents of proteins extracted from fresh lucerne are 1.5 per cent and 1.45 per cent, while those of the proteins extracted from sun-dried lucerne are lower, being 1.03 per cent and 0.75 per cent respectively[11]. Lucerne grown in culture solutions free from sulphur compounds builds up proteins richer in arginine but poorer in the other essential amino acids[12]. Reports in the literature on the lysine content of lucerne proteins vary widely[6, 10, 13].

Nutritive value: Lucerne proteins possess a medium biological value[14, 15], comparable to groundnut proteins, but distinctly higher than that of clover (*Medicago lupulina*) proteins[15]. Supplementation with methionine at 0.2 per cent level increases the nitrogen utilisation by 30 per cent[16]. On dehydration, the nutritive value of lucerne proteins is reported to decrease in proportion to the temperature and time of drying[17].

Digestibility: Values reported in the literature for the digestibility of lucerne proteins vary widely[14, 15, 18]. There is evidence to indicate that the human intestinal tract can efficiently utilise the protein in lucerne preparations[4].

Supplementary value: Subrahmanyan and Sur[19, 20] found that dried lucerne, even at low levels, possesses a phenomenal supplementary value to the poor rice diet. The gross supplementary value to poor rice diet of aqueous lucerne extract, dried at a low temperature, has been demonstrated[21]. Lucerne proteins supplement the proteins of rice[22] and of whole yellow corn[16].

Processing and utilisation: The use of lucerne as human food has been much advocated[3, 4, 18, 24, 25]. Arabs, it is reported[23], resort to consumption of lucerne during conditions of famine. Its bitter taste and strong odour[4, 18, 21, 25] are the major impediments to the use of lucerne as human food. Suggestions for overcoming these defects include extraction of the bitter principles with hot water as well as the cultivation of varieties of lucerne free from the undesirable characteristics[4]. Specific recipes have been formulated to help ingesting at least 50 grams of tender lucerne with the daily dietary[26]. It is reported that lucerne can be consumed in the form of green salad[24]. A method has been described for masking the bitter taste by cooking lucerne into a spinach-like substance[18].

Lucerne flour is brilliant green in colour and has an average protein content of 33 per cent[25]. It possesses a faint, pleasant, coumarin-like odour, reminiscent of new-mown hay[25]. On boiling the flour in water for a minute, the original odour is reported to give place to a legume-like aroma, suggestive of green peas[25]. The cost of production of lucerne flour is estimated to be £ 30 per ton[21].

A method has been standardised for the preparation and tableting of fibre-free lucerne concentrate[21]. Recipes for the incorporation of fresh lucerne[26], lucerne flour[25], as also lucerne concentrate[21] in soups have been suggested.

Other Leaves

The leaves of a wide range of plants other than lucerne have been reported to form part of the dietary of native populations in Mexico[27] and in East[28] and South[29] Africa. Tapioca leaves are consumed extensively in Java[30]. Tender leaves are generally preferred in view of their low fibre content, but in the case of turnip greens (*Brassica rapa*) palatability is not related to the stage of growth[31].

Protein content: The protein content of leaves has been reported to vary widely with species, from 10 per cent in strawberry leaves (*Fragaria vesca*) to 39 per cent in bryony leaves (*Bryonia dioica*) on the dry weight basis[34]. A considerable proportion of the total nitrogen of leaves is non-protein[32, 33]. Vegetable matter arising as wastes or

temporary surpluses (in the United States) has been found by analysis to be low in crude fibre and high in protein; the protein content ranges from 13 per cent (lima bean vines) to 43 per cent (broccoli)[35]. Water-hyacinth (*Eichornia crassipus*) has a fairly high protein content[36]. Among eight kinds of leaves commonly consumed in South India, Mukarattai (*Boerhavia repens*), Kuppameni (*Acalyapha indica*) and Nerringi (*Tribulus terrestris*) have been reported to contain large amounts of protein, of the order of 35 per cent to 39 per cent on the dry weight basis[37]. Tapioca leaves contain as much as 8 to 10 per cent protein even on the fresh weight basis[30, 38]; the leaves from certain varieties are, however, associated with cyanogenetic glucosides which require to be eliminated through proper processing[30]. Groundnut leaves also possess a high protein content[39]. Flour from dried lime leaves (*Citrus aurantifolia*), reported to be used as human food in admixture with barley flour, contains 17 per cent protein, 18 per cent of which is digested by trypsin[40].

In general, the protein content of leaves decreases with maturity[31]. The proportion of protein that could be extracted from different leaves[7, 34, 41, 42], as also the percentage yields of dry protein[43], have been investigated. On an average, 75 per cent of the total nitrogen is reported to be extractable from leaves[34]; this value varies widely from 23 per cent in the case of tapioca leaf[41] to 94 per cent in the case of tobacco leaf[34, 42]. The percentage nitrogen extracted varies directly with the total nitrogen content of the leaves[34] and more particularly with the true protein nitrogen[7]; on the other hand, it varies inversely as the dry matter content[34].

Amino acid composition: The amino acid composition of the proteins extracted from the leaves of a number of Indian trees has been reported[41]. According to the earlier work of Chibnall[44], Tristram[45] and Lugg and Weller[9, 13], there is not much species or seasonal variation in the amino acid composition of leaf proteins. Also, according to Kelley and Baum[46], the proteins in different species of leaves contain similar amounts of the essential amino acids. But, recent work by Armstrong[10] points to the possibility of a wider variation in the amino acid composition of herbage proteins than is normally supposed. The proteins of leaves are, in general, well balanced with respect to the essential amino acids[41, 46], including lysine[13, 41, 45] and the sulphur amino acids[47]. The amino acid composition does not change materially during the process of extraction of the protein from the whole leaves[9]. The onset of senescence brings about an increase in the cystine and tyrosine contents and a decrease in the methionine content of the whole protein in the leaf material[48].

Nutritive value: The proteins of spinach leaves are reported to be digested at a significantly slower rate than is casein[49]. The proteins of rami leaf meal (*Boehmeria nivea*) have a high nutritive value[50],

but not clover proteins[15]. Among the leaves of legumes, those of soya bean in the full-pod stage are reported to contain proteins of high biological value[51].

Processing: Processing of whole leaves into edible flour for human consumption has been reported only in the cases of tapioca[30], oats[52] and lime[40] (*Citrus aurantifolia*). Leaves and grasses, though generally rich in proteins, also contain too much of fibrous and other indigestible matter to be of direct use as human food[53]. The separation of the edible from the inedible portion has long been a major problem in this line[53, 54]. A few attempts have been made to process herbage on a small scale with a view to using the proteins as animal feed or human food in different forms[1, 2, 39, 53, 55-60]. Though the potentialities in this direction are considerable, the possibility of herbage as such finding a major place in the human dietary still remains to be explored by careful experimentation[61].

Two independent lines of approach to the problem would be, firstly, the extraction of protein from leaf wastes and secondly, a more beneficial use of leaves that are now being grown mainly for animal feeding[53]. It is estimated that in the United States alone, some two million tons of leaf wastes, containing 50,000 tons of protein, arise every year from the commercial farming of vegetable crops[62]. A process, with cost estimates, has been described for the production of protein concentrates from these wastes using a type of direct-fired rotary drier[63], but in so far as the extraction of protein itself is concerned, comparatively little attention has been paid to these vegetable wastes[53].

The necessity of having to extract protein from herbage arises from the fact that the animal is an uneconomical converter of leaf nitrogen into its body protein, however suitable the latter type may be for human consumption[1, 53]; the efficiency of conversion can be as low as 10 per cent and never exceeds 40 per cent[53]. Much more protein would become available if palatable protein concentrates could be made directly from herbage[1]. The processing should aim at skimming off part of the protein of the leaf in a form suitable for consumption by human beings, while leaving the remainder in the residue which can be used as feeding stuff for ruminants[56].

Pioneering work in this field has mostly come from Pirie and associates[2, 53, 55, 56] at Rothamstead and from the I.C.I. group led by Slade[1, 57-59]. Pirie regards processing herbage proteins for direct human consumption to be essentially a bio-engineering problem[55]. According to his procedure[2, 53, 55, 56], soluble proteins equivalent to 30 to 35 per cent of the original nitrogen in the leaf are extracted, leaving the rest therin for the use of farm animals. This is achieved by macerating the fresh leaves, filtering off the protein-rich liquor from the leaf residue and separating the protein by one of the many commonly available treatments such as heat coagulation or acidification[2, 53, 56].

Solvent extraction of the protein removes the pigments and lipids and gives a pale, stable powder[53]. Pirie[53] considers leaves of the sugarcane (*Saccharum officinarum*) and of the sisal (*Agave sisalina*), so abundantly available in tropical and subtropical countries, to be pre-eminently suited to processing for proteins. Cabbage leaves[2], corn leaves[56], lucerne[2, 56] and grass[2, 56] are also excellent raw materials for protein extraction. According to Pirie, extracted leaf protein should cost less than other proteins being produced in Great Britain[56]. He claims for this method of husbandry several advantages, like larger yields of protein of higher biological value than are attainable from an acre of land by any other means and a residue of relatively constant composition and of considerably greater feeding value than the hay which otherwise is the normal end product[56]. Laboratory experience with the processing of a wide range of leaves shows that most of them behave in a very similar manner and difficulties are seldom encountered in protein extraction unless the leaves are withered or naturally have a low water content[53].

As early as 1939, Slade and associates obtained a patent for preparing from herbage material protein concentrates containing small quantities of carbohydrate[57]. Later they effected certain improvements in the process by way of treatment of the product with an aqueous solution of a weak alkali such as sodium carbonate, in order to reduce, if not remove the unpleasant-tasting ingredients[58]. A modification worked out by the same group is to treat macerated foliage at a temperature of 40-60°C with a proteolytic enzyme activated by sodium sulphide, thereby obtaining a clear protein hydrolysate[59].

Protein production from leaves has been investigated by a number of other workers too. In India, the first attempts to obtain proteins from leaves in a form suitable for human consumption were made by Guha[60] and associates at the time of the Bengal famine in 1943. These different investigations contain several practical hints which would be of value to future workers in the field. A preliminary grinding in a mincer, followed by grinding in a triple roller mill, has been recommended[42]. The effects of freezing, alkalinity of the extracting fluid, buffers, salt solutions and detergents on the extraction process are detailed and the conditions optimum for protein production have been standardised in the case of tobacco leaf[42]. This work has later been extended to twenty-eight species of leaves[34]. An elegant method for the removal of chlorophyll from leaf extracts has been described[64]. Release of protoplasts after a two-day fermentation of the cell walls is considered to be a desirable first step in the extraction of protein from leaves, because it is said to bring about two- to seven-fold increase in the protein concentration over that of the original material[62]. An American patent subjects the hot water extract of leaves and stems to microbial action, followed by a number of processes of filtration and sedimentation in order to obtain a protein-rich material[65].

Protein content: The crude protein content of ten species of Indian grasses has been reported to vary from 6.9 per cent (spear-grass *Heteropogon contortus*) to 9.0 per cent (barki: *Themeda tremula*); on an average, 90 per cent of the total crude protein is true protein[66]. Dhurba grass (*Graminae*) contains 15.6 per cent protein[36]. The average crude protein content of winter barley grass, oats grass, wheat grass and annual rye grass (*Lolium perenne*), periodically clipped whenever grazing height is reached, is of the order of 20 per cent; nearly a third of the total nitrogen is accounted for by non-protein constituents[67].

Differences in the protein content of grass due to species are small compared with differences due to stages in growth[68]. That protein content decreases with maturity, has been shown clearly in the case of Italian rye grass[68] (*Lolium italicum*), jowar grass[69] and other grasses of Indian origin[70]. The protein content of tufted hair grass (*Deschampsia caespitosa*) is 8.5 per cent after the appearance of the panicle and drops to 5.9 per cent at the beginning of the blooming period and to 5.3 per cent thereafter; harvesting before blooming is thus indicated for being used as fodder[71]. Prairie hays, cut early, have 30 per cent to 50 per cent more protein than late cut hays and yield on an average 400 lb more dry matter and 50 lb. more protein per acre[72]. Further it has been observed that the protein content of grasses is maximum at or near the start of the growing season and diminishes progressively as they mature; it decreases from an average of 20.2 per cent in April to 5.5 per cent in November[73].

The proportion of protein that could be extracted from different grasses[7, 34] and the percentage yields of dry protein[43, 74] have been investigated.

Amino acid composition: The amino acid composition of grass proteins has been reviewed[75]. In view of their high lysine content [76-78], the proteins of grass should prove a valuable supplement to cereal proteins; the high valine content[76, 77, 79] should, in addition, prove useful in correcting this deficiency in diets based predominantly on wheat. The proteins of certain grasses like timothy (*Phleum pratense*) are also rich in tryptophan[10].

Reber and MacVicar[76, 77] did not observe any marked variations in the amino acid composition of different cereal grasses. The basic amino acid content of grass proteins[78], as well as the sulphur amino acid content[80], varies little with the species. On the contrary, Smith and Agiza[79] have drawn attention to a number of consistent differences in amino acid make-up between species sampled on the same date or approximately of the same age.

Grass proteins are reported to be deficient in cystine[8, 10, 80] to a greater extent than lucerne proteins[8]. According to Armstrong[10], however, the low values reported for cystine in grass proteins can

actually be due to faulty methods of hydrolysis. Grass proteins are also deficient in methionine[10, 76, 77, 80].

Factors like season of cutting and stage of maturity have been implicated in the relative make-up of amino acids in grass proteins[77, 79, 80]. In general, the first growth contains more arginine, leucine and isoleucine but less glutamic acid than the second growth[79]. Isoleucine increases considerably with maturity (20 per cent to 30 per cent) and tryptophan remains more or less stationary, while lysine and threonine decrease markedly (50 per cent) and the other essential amino acids decrease at a slower rate[77]. Aspartic and glutamic acids increase, while arginine and lysine decrease as growth approaches seed formation[79]. According to another report[80], samples of grass that have passed the flowering stage are relatively richer in the sulphur amino acids. Application of nitrogenous fertilizers increases the proportion of a number of essential amino acids[79].

Nutritive value: Grass proteins have been reported to possess, in general, a higher nutritive value than the proteins of leguminous leaves[51]. Using the guinea pig growth-method, Thomas and Armstrong[81] have shown that (*i*) the protein in grass from temporary ley maintains its quality irrespective of season and is, at all times, superior to the proteins in permanent grass: and that (*ii*) the proteins in cocksfoot grass (*Dactylis glomerata*) are superior to those in Italian rye grass as judged by weight gain per unit protein ingested, but inferior as judged by weight gain per unit protein digested. By a similar experimental technique, Elephant grass (*Pennisetum purpureum*) and Guatemala grass (*Tripascum latifolium*) have been shown to be superior in nutritive value to Cana Uba grass[82] (*Saccharum officinarum*).

Using the classical nitrogen-balance method and albino rats as the experimental animal, Davis *et al.*[83] have shown that, while the biological value of the proteins from young grass of different species is nearly the same, the biological value as also the digestibility decreases with increasing maturity. They further report that of the whole grass proteins, the cytoplasmic fraction has a biological value of 60.7 per cent and a digestibility of 74.8 per cent, while the chloroplastic fraction has a biological value of only 46.0 per cent and a digestibility of 61.2 per cent[83]. That the digestibility of grass proteins decreases with maturity has also been shown by a number of other workers[68, 72].

It has been reported that there is little difference between the protein quality of fresh and artificially dried grass[84]. The temperature of drying has no effect on the nutritive value of grass proteins, but artificially dried grass is definitely superior in protein quality to sun-cured hay[85]. The presence in grass of a factor ('grass juice factor') essential for maintenance and growth in guinea pigs has been reported[86]. Young grass tissues are much richer in this factor than the older and more mature material[87].

Processing: Grass juice has been successfully spray-dried[88]. A product suitable for poultry feeding obtained by mechanically communiting fresh grass has been described; it has a pasty consistency and is claimed to contain all the proteins present in the protoplast[89]. As in the case of the proteins of green leaves, grass proteins also need to be freed from fibre in the first instance, before being considered for human consumption. There is a stray reference in the literature to the consumption of grass as such by human beings in Japanese prisons[90].

Successful experiments on the extraction of proteins from grass on a laboratory scale have been described by Chibnall *et al.*[43] and on a large scale, by Slade[1, 57-59] and associates and Hughes and Eyles[91]. The production of protein concentrates from air-dried clippings of young grass has been investigated by Sullivan[74, 92]. The protein is extracted by alkali, precipitated by adjusting the pH of the clear extract to 3.6, filtered, washed and dried. The yield of dried protein is about 13 per cent on the weight of the original material. On extraction with rectified spirit, most of the adhering chlorophyll is removed and a dark, tasteless powder results with an enhanced protein content of 72 per cent, but corresponding in yield to only about 10 per cent of the weight of the original material[74, 92]. Fibre-free grass protein concentrate has been shown to be as good a supplement to poultry rations as fish meal[93], but its value in human nutrition still remains to be assessed.

TABLE XXII

NUTRITIVE VALUE OF LEAF AND GRASS PROTEINS

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Nutritive Value: Coefficient of true digestibility %	Nutritive Value: Protein efficiency ratio
Lucerne (alfalfa)					
Lucerne (*Medicago sativa*)[18] ...	...	...	...	94·5-96·1	...
Lucerne, advanced leafy stage[15] ...	23·0	10	54·9	83·5	...
Lucerne meal[14] ...	...	...	60·5	74·0	...
Lucerne hay[94] ...	...	10	62·0	58·0	...
Other leaves					
Leguminous plant leaves[51]	...	...	32·0-63·0	...	...
Trefoil, early flowering stage (*Medicago lupulina*)[15] ...	20·6	10	45·1	75·8	...
Grasses					
Cocksfoot grass protein, chloroplastic fraction (*Dactylis glomerata*)[83] ...	41·6	10	46·0	61·2	...
Cocksfoot grass protein, cytoplasmic fraction[83]	71·4	10	60·7	74·8	...
Mixed forage					
Wild white clover and perennial rye grass (*Trifolium repens* and *Lolium perenne*), sun dried under natural conditions (hay)[85] ...	25·1	9	51·9	64·4	...
Wild white clover and perennial rye grass, artificially dried at low temp. (170°F)[85] ...	23·1	9	62·2	65·2	...
Wild white clover and perennial rye grass, artificially dried at the normal running temp. (300°F)[85] ...	23·5	9	67·2	65·7	...

TABLE XXIII. AMINO ACID COMPOSITION

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Lucerne (alfalfa)						
Lucerne (*Medicago sativa*)[95]	...	4·3	2·1	4·9	5·7	1·6
Lucerne[96] ...	18·1	3·1	1·2	4·9	...	1·4
Lucerne (composite sample from 100 clones of different genetic backgrounds)[6] ...	19·6	3·5	1·5	4·2	1·8	1·5
Lucerne, preflowering[10] ...	21·2	...	...	2·1	2·3	1·4
Lucerne, normal third cutting (receiving nutrient solution containing sulphate)[12] ...	17·8	5·3	2·0	5·0	2·4	2·1
Lucerne, normal third cutting (receiving the same nutrient solution without sulphate)[12] ...	18·8	5·5	1·3	2·8	1·3	0·9
Lucerne, protein, extracted[9, 13] ...	88·4	7·0	2·2	5·3	4·8	2·3
Lucerne, protein, extracted[45] ...	90·0	7·5	1·4	5·8	...	...
Lucerne, protein, extracted[47] ...	87·5	...	...	...	...	...
Lucerne, protein, extracted[79] ...	79·4-98·8	1·3-1·5	...	1·8-1·9	4·1-4·4	1·1-1·3
Lucerne, protein, extracted (average of 2 samples)[8] ...	94·4	...	...	...	...	...
Lucerne, (fresh) protein, extracted[11] ...	...	...	...	...	...	...
Lucerne, (sun dried) protein, extracted[11] ...	...	...	...	...	...	...
Lucerne protein (whole protein less N.P.N. fraction)[9]	42·4	...	...	...	5·0	2·3
Other leaves						
Aparajita leaf protein (*Clitoria ternatea*)[41] ...	52·7	6·0	2·0	5·4	5·1	1·9
Beet leaf protoplast (*Beta vulgaris*)[46] ...	40·9	5·9	1·9	5·6	...	1·7
Beet leaf meal[46] ...	24·3	4·1	1·3	5·4	...	1·2
Beet spinach protein, extracted (*Beta cicla*)[15] ...	91·3	6·4	1·3	5·6	...	...
Broccoli leaf (fat-free) protoplast (*Brassica oleracea*)[46] ...	78·2	5·2	1·8	5·3	...	2·3
Broccoli leaf meal[46] ...	41·0	4·8	1·5	4·5	...	1·4
Broccoli leaf protein[46] ...	...	6·0	2·2	5·5	...	...
Burr medic protein extracted (*Medicago denticulata*)[9, 13] ...	90·9	6·5	2·3	5·4	5·0	2·2
Burr medic protein (whole protein less N.P.N. fraction)[9] ...	42·9	...	...	...	5·0	2·2

* (C: Chemical; CC: Chromatographic;

ACIDS							Method of Estimation*
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
4·5	1·6	2·3	3·3	6·6	3·6	4·4	MM
4·1	...	0·2	3·3	6·6	3·6	4·4	M
4·1	1·7	1·3	5·0	7·9	4·3	4·9	M
...	0·4	1·0	...	...	...	...	M
5·4	2·6	1·6	6·5	10·2	4·8	6·1	M
2·8	1·0	0·8	3·0	5·0	2·9	3·3	M
...	1·6	2·3	...	...	...	...	C
...	...	...	...	...	...	...	C
...	1·7	2·2	...	...	...	...	C
4·7-5·1	...	...	4·5-5·0	...	...	5·6-7·8	CC
...	1·0	...	...	...	...	...	C
...	1·5	1·5	...	...	...	...	...
...	1·0	0·8	...	...	...	...	...
...	1·6	2·1	...	...	...	...	C
5·2	1·4	1·8	5·0	...	...	6·6	CC
6·5	...	1·6	4·9	8·6	5·5	6·3	M
5·8	...	1·7	3·8	6·4	4·2	5·1	M
...	...	...	...	...	...	...	C
7·8	...	1·8	4·4	8·9	4·7	5·9	M
6·0	...	1·8	3·3	6·4	3·2	4·5	M
7·5	...	2·0	5·0	9·2	5·3	6·4	M
...	1·7	2·2	...	...	...	...	C
...	1·6	2·1	...	...	...	...	C

M: Microbiological; MM: Miscellaneous).

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Carrot leaf protoplast (*Daucus carota*)[46] ...	27.0	6.9	2.0	5.5	...	2.2
Carrot leaf meal[46] ...	19.6	4.3	1.9	4.5	...	1.4
Carrot leaf protein[46] ...	...	5.7	2.1	5.4	...	...
Castor leaf protein, extracted (*Ricinus communis*)[45] ...	78.4	6.4	1.3	5.4	...	...
Celery leaf meal (*Apium graviolens*)[46] ...	23.2	4.0	1.5	2.4	...	1.3
Chantkata leaf protein (*Cassia* sp.)[41] ...	45.8	5.7	2.1	5.2	5.2	2.0
Chicory leaves, preflowering (*Cichorium intybus*)[10] ...	10.9	...	1.5	3.2	2.5	1.5
Clover, mature (*Trifolium subterraneum*)[97] ...	44.8	...	...	...	5.2	2.0
Clover (mature) protein, extracted[97] ...	88.1	...	...	...	5.5	1.9
Clover, senescent[48] ...	19.8	...	...	...	5.8	2.2
Clover (senescent) protein extracted[48]	82.2	6.7	2.5	4.8	5.8	2.1
Clover (Alsike) leaves, preflowering (*Trifolium hybridum*)[10] ...	20.3	...	2.0	3.9	2.5	1.8
Clover, Red, leafy (*Trifolium pratense*)[79] ...	...	2.5	...	3.3	...	...
Clover, Red, early-flowering[79] ...	...	2.3	...	2.5	...	...
Clover, Red, late-flowering[79]	...	2.0	...	2.1	...	...
Clover, Red, protein, extracted[8] ...	78.8	...	...	...	...	...
Clover, Red, protein, extracted[45] ...	80.9	7.4	1.4	5.4	...	...
Clover, Red, protein, extracted[79] ...	65.0-100.0	2.0-2.5	...	2.1-3.5	4.4-7.0	1.3-1.5
Clover, white (young), protein, extracted (*Trifolium repens*)[80] ...	77.3	...	...	...	...	...
Clover, White, (old), protein, extracted[80] ...	73.1	...	...	...	...	...
Clover, White wild, protein, extracted (*Trifolium repens*)[8] ...	82.5	...	...	...	...	...
Clover, White, wild, protein, extracted[45] ...	83.1	7.7	0.9	5.5	...	...
Corn leaf meal (*Zea mays*)[46]	19.4	3.9	1.3	3.2	...	1.3
Corn leaf protein, extracted[45]	87.2	7.2	1.2	5.1	...	...
Gandal leaf protein (*Paederia foetida*)[41] ...	44.6	4.9	2.1	3.8	5.1	1.9
Groundnut leaf protein (*Arachis hypogea*)[41] ...	54.1	5.9	2.2	5.2	5.7	2.1
Kale leaf meal (*Brassica oleracea*)[46] ...	24.7	5.1	1.6	3.1	...	1.1
Krishnachura leaf protein (*Caesalpinia pulcherrima*)[41]	61.9	5.8	2.2	5.2	5.7	1.8
Lima bean leaf protoplast (*Phaseolus lunatus*)[46] ...	48.4	5.5	1.5	3.8	...	1.7

ACIDS							Method of Estimation
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
8·4	...	1·8	6·1	10·7	6·3	7·2	M
6·5	...	1·7	4·4	7·1	4·5	5·5	M
7·7	...	3·4	5·0	10·6	5·5	7·0	M
...	...	...	...	...	...	...	C
4·5	...	2·2	3·4	6·8	3·9	4·8	M
5·0	1·5	1·9	4·3	...	...	7·0	CC
...	0·4	0·8	...	...	...	...	M
...	1·6	2·2	...	...	...	...	C
...	1·5	2·2	...	...	...	...	C
...	1·9	1·8	...	...	...	...	C
...	2·0	1·0	...	...	...	...	C
...	0·4	1·0	...	...	...	...	M
5·6	...	...	...	...	...	8·2	CC
5·3	...	...	...	...	...	8·2	CC
4·3	...	...	...	...	...	7·2	CC
...	0·2	...	...	...	...	...	C
...	...	...	...	...	...	...	C
4·1–5·8	...	...	4·9–6·4	...	...	7·1–8·4	CC
...	1·5	2·1	...	...	...	...	C
...	1·8	2·4	...	...	...	...	C
...	0·3	...	...	...	...	...	C
...	...	...	...	...	...	...	C
5·4	...	2·8	3·3	6·9	3·6	4·8	M
...	...	...	...	...	...	...	C
6·8	1·4	2·1	4·3	...	...	7·0	CC
6·0	1·7	1·7	4·6	...	...	6·7	CC
4·4	...	0·9	3·5	6·5	3·4	4·6	M
4·9	1·3	2·0	4·3	...	...	7·0	CC
7·4	...	1·2	4·6	8·0	4·7	5·6	M

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Trypto-phan %
Lima bean leaf meal[46] ...	16·9	4·2	1·3	3·6	...	1·4
Lima bean leaf protein[46] ...	...	5·7	1·9	5·2	...	...
Pea leaf meal (*Pisum sativum*)[46] ...	23·6	4·6	1·6	4·9	...	1·5
Pea vine protein[46] ...	...	5·4	1·8	5·8	...	...
Plantin leaves, narrow-leaved, early flowering (*Plantago lanceolata*)[10] ...	8·5	...	1·8	3·5	3·8	1·6
Radhachura leaf protein (*Poinciana regia*)[41] ...	59·2	5·7	2·1	5·1	5·6	1·9
Rhubarb leaf meal (*Rheum raphonticum*)[46] ...	26·1	4·7	1·9	5·4	...	1·6
Rhubarb leaf protein[46] ...	...	6·3	2·4	5·4	...	...
Rutabaga leaf protein (*Brassica napobrassica*)[46] ...	...	5·4	1·7	5·6	...	...
Sainfoin leaves, early-flowering (*Onobrychis sativa*)[10] ...	20·9	...	...	3·6	3·3	1·4
Sonali leaf protein (*Peltophorum ferrugineum*)[41] ...	54·7	5·8	1·9	5·4	5·2	2·0
Spinach leaf meal (*Spinacia oleracea*)[46] ...	25·7	4·4	1·3	4·7	...	1·1
Spinach leaf protein[46] ...	...	5·4	1·8	5·8	...	...
Spinach leaf protein, extracted[45] ...	96·3	7·0	1·3	5·2	...	...
Turnip leaf meal (*Brassica rapa*)[46] ...	23·9	4·5	1·4	3·0	...	1·3
Yarrow leaves, early flowering (*Achillea millefolium*)[10]	8·1	...	1·9	4·3	3·3	1·9
Grasses						
Barley grass, early flowering (*Hordeum vulgare*)[79] ...	...	1·9	...	2·6	...	...
Barley grass, flowering[79] ...	...	1·8	...	2·4	...	...
Barley grass, seeding[79] ...	...	1·7	...	2·0	...	...
Barley grass protein, extracted[9, 13] ...	88·1	7·1	2·1	5·3	4·8	2·3
Barley grass protein (whole crude protein less N.P.N. fraction)[9] ...	39·2	...	...	...	4·9	2·4
Bent grass protein, extracted (*Agrostis* sp.)[8] ...	64·4	...	...	...	...	...
Bracken protein, extracted (*Pteris aquilina*)[79] ...	65·0-86·3	1·1-1·5	...	2·2-2·3	3·3-4·1	Nil
Cocksfoot grass, preflowering (*Dactylis glomerata*)[10] ...	13·5	...	...	4·5	4·0	1·6
Cocksfoot grass protein, extracted[8] ...	84·9	...	...	...	...	...

ACIDS							Method of Estimation
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
7·0	...	1·2	4·0	6·6	3·6	5·0	M
7·0	...	2·2	4·7	9·1	5·2	5·9	M
6·0	...	1·0	4·4	7·8	4·4	5·7	M
6·7	...	1·8	4·5	8·7	5·1	6·1	M
...	0·6	1·3	...	...	...	...	M
4·8	1·5	2·0	4·3	...	...	6·9	CC
6·1	...	1·0	4·0	8·4	4·0	5·3	M
6·9	...	2·1	4·6	9·8	5·0	6·6	M
5·8	...	1·6	4·2	7·2	4·7	6·0	M
...	0·4	1·0	...	...	...	...	M
5·5	1·5	2·0	4·9	...	...	7·0	CC
4·7	...	2·3	3·9	6·8	3·6	5·0	M
5·8	...	1·8	4·6	8·2	4·2	6·0	M
...	...	...	...	...	...	...	C
5·3	...	2·2	4·0	6·8	3·9	4·8	M
...	0·6	1·4	...	...	...	...	M
3·4	...	...	...	...	...	5·9	CC
3·6	...	...	...	...	...	6·6	CC
3·2	...	...	...	...	...	6·7	CC
...	1·8	2·4	...	...	...	...	C
...	1·8	2·3	...	...	...	...	C
...	0·2	...	...	...	...	...	C
2·4-3·0	...	...	3·3-3·7	...	...	8·2-8·8	CC
...	0·4	1·6	...	...	...	...	M
...	0·3	...	...	...	...	...	C

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Cocksfoot grass protein, extracted[45] ...	84·7	7·4	1·4	5·1	...	...
Cocksfoot grass protein, extracted[47] ...	83·3	...	...	...	...	...
Cocksfoot grass protein, extracted[98] ...	83·8	...	...	...	...	...
Cocksfoot grass (young) protein, extracted[80] ...	79·4	...	...	...	...	...
Cocksfoot grass (young spring) protein, extracted[78] ...	90·6	7·3	1·5	4·8	...	...
Cocksfoot grass (young autumn) protein, extracted[78] ...	88·8	8·1	1·4	5·1	...	...
Cocksfoot grass (old) protein, extracted[80] ...	65·0	...	...	...	...	...
Cocksfoot grass (old autumn) protein, extracted[78] ...	49·4	7·6	1·3	6·3	...	...
Crested dogs' tail grass, early flowering (*Cynosurus cristatus*)[10] ...	8·0	...	1·6	4·3	2·7	1·8
Crested dogs' tail grass protein, extracted[8] ...	93·1	...	...	...	...	...
Crested dogs' tail grass protein, extracted[45] ...	89·4	7·5	1·5	4·8	...	...
Draw moss grass, flowering (*Eroiphorum vaginatum*)[10]	12·4	...	...	3·8	2·7	1·5
Fescue, Chewings, protein, extracted (*Festuca rubra*)[8]	87·5	...	...	...	...	...
Fescue, Chewings, protein, extracted[45] ...	90·9	7·2	1·2	4·6	...	...
Fescue, Hard, protein, extracted (*Festuca duriuscula*)[8] ...	91·3	...	...	...	...	...
Fescue, Meadow, protein, extracted (*Festuca pratensis*)[8] ...	86·9	...	...	...	...	...
Fescue, Meadow (young spring), protein, extracted[78] ...	95·9	6·9	1·5	6·5	...	...
Fescue, Meadow (young autumn), protein, extracted[78] ...	91·3	7·3	1·5	6·4	...	...
Fescue, Meadow (old autumn), protein, extracted[78] ...	50·0	7·1	1·2	5·8	...	...
Fescue, Red, early-flowering (*Festuca rubra*)[10]	6·4	...	...	2·5	3·4	1·7
Fescue, Red, protein, extracted[8] ...	88·8	...	...	...	...	...
Fescue, Tall, protein, extracted (*Festuca elatior*)[8]	85·0	...	...	...	...	...
Meadow grass, rough-stalked, protein, extracted (*Poa trivialis*)[8]	86·3	...	...	...	...	...

ACIDS							Method of Estimation
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
...	...	...	...	...	...	...	C
...	2·0	2·5	...	...	...	...	C
...	0·1	1·7	...	...	...	...	C
...	1·8	2·7	...	...	...	...	C
...	...	...	...	...	...	...	CC
...	...	...	...	...	...	...	CC
...	2·0	2·4	...	...	...	...	C
...	...	...	...	...	...	...	CC
...	0·5	2·1	...	...	...	...	M
...	0·8	...	...	...	...	...	C
...	...	...	...	...	...	...	C
...	0·3	1·6	...	...	...	...	M
...	0·9	...	...	...	...	...	C
...	...	...	...	...	...	...	C
...	0·9	...	...	...	...	...	C
...	0·8	...	...	...	...	...	C
...	...	...	...	...	...	...	CC
...	...	...	...	...	...	...	CC
...	...	...	...	...	...	...	CC
...	0·6	1·3	...	...	...	...	M
...	0·9	...	...	...	...	...	C
...	0·7	...	...	...	...	...	C
...	0·3	...	...	...	...	...	C

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Meadow grass, rough-stalked, protein, extracted[45] ...	86·6	7·9	1·3	4·6	...	...
Molinia grass, flowering (*Molinia coerulea*)[10] ...	14·5	...	...	4·0	4·2	1·3
Oats grass, small stems (*Avena sterilis*)[79] ...	...	1·5	...	1·9	...	...
Oats grass, flowering[79] ...	...	1·2	...	1·4	...	...
Oats grass, seeding[79] ...	...	1·1	...	1·2	...	...
Old man salt-bush protein, extracted (*Atriplex nummularium*)[17] ...	75·6	...	...	...	...	...
Rye grass, annual (*Secale cerealle*)[76] ...	26·3	...	...	5·6	...	1·0
Rye grass, Italian, preflowering (*Lolium italicum*)[10] ...	12·8	...	...	3·9	3·3	1·6
Rye grass, Italian, leafy[79] ...	...	2·1	...	2·6	...	...
Rye grass, Italian, flowering[79] ...	...	2·0	...	2·4	...	...
Rye grass, Italian, seeding[79]	...	1·5	...	1·8	...	...
Rye grass, Italian, protein, extracted[8] ...	87·5	...	...	...	...	...
Rye grass, Italian, protein, extracted[45] ...	88·1	6·7	1·4	4·9	...	...
Rye grass, Italian, protein, extracted[79] ...	60.6-93.8	1.5-2.1	...	1·8-2·8	3.5-5·6	0·8-1·4
Rye grass, Perennial, early-flowering (*Lolium perenne*)[10] ...	7·0	...	...	3·4	4·2	1·8
Rye grass, Perennial, protein, extracted[8] ...	79·4	...	...	...	...	...
Rye grass, Perennial, protein, extracted[45] ...	83·6	7·0	1·4	5·0	...	...
Rye grass, Perennial (young), protein, extracted[80] ...	62·5	...	...	...	...	...
Rye grass, Perennial (young spring), protein, extracted[78] ...	93·5	7·2	1·7	5·9	...	...
Rye grass, Perennial (young autumn), protein, extracted[78] ...	91·9	7·7	1·5	5·8	...	...
Rye grass, Perennial (old), protein, extracted[80] ...	45·6	...	...	...	...	...
Rye grass, Perennial (old autumn), protein, extracted[78] ...	71·3	7·8	1·5	6·2	...	...
Stool-bent grass, flowering (*Juncus squarrosus*)[10] ...	10·6	...	...	4·0	3·5	1·7
Timothy grass, pre-flowering (*Phleum Pratense*)[10] ...	8·8	...	2·1	4·2	2·3	2·1
Timothy grass protein, extracted[8] ...	86·3	...	...	...	...	...

ACIDS							Method of estimation
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
...	...	...	...	...	...	...	C
...	0·6	1·9	...	...	...	...	M
5·5	...	...	...	...	...	9·0	CC
5·1	...	...	...	...	...	7·1	CC
4·0	...	...	...	...	...	5·9	CC
...	2·0	2·6	...	...	...	...	C
4·5	...	1·1	7·8	8·8	6·2	5·0	...
...	0·4	1·7	...	...	...	...	M
4·7	...	...	...	...	...	8·3	CC
4·7	...	...	...	...	...	7·9	CC
4·3	...	...	...	...	...	7·5	CC
...	0·7	...	...	...	...	...	C
...	...	...	...	...	...	...	C
3·8-4·9	...	...	3·8-5·2	...	...	6·4-8·6	CC
...	0·8	1·4	...	...	...	...	M
...	0·5	...	...	...	...	...	C
...	...	...	...	...	...	...	C
...	1·4	2·2	...	...	...	...	C
...	...	...	...	...	...	...	CC
...	...	...	...	...	...	...	CC
...	1·6	2·6	...	...	...	...	C
...	...	...	...	...	...	...	CC
...	0·5	1·6	...	...	...	...	M
...	0·5	1·7	...	...	...	...	M
...	0·3	...	...	...	...	...	C

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Timothy grass (young) protein, extracted[80] ...	50·0	...	...	...	...	...
Timothy grass (young spring) protein, extracted[78] ...	88·8	7·2	1·6	6·2	...	...
Timothy grass (young autumn) protein, extracted[78] ...	90·0	6·6	1·3	5·6	...	...
Timothy grass (old) protein, extracted[80] ...	69·4	...	...	...	...	...
Timothy grass (old autumn) protein, extracted[78] ...	83·1	6·5	1·7	5·3	...	...
Toowamba Canary grass protein, extracted (*Phalaris tuberosa*)[9, 13] ...	93·1	6·8	2·2	5·5	4·8	2·4
Toowamba Canary grass protein, extracted[47] ...	96·1	...	...	...	...	...
Toowamba Canary grass protein (whole crude protein less N.P.N. fraction)[9]	37·8	...	...	...	5·0	2·4
Yorkshire fog protein, extracted (*Holcus lanatus*)[8]	73·8	...	...	...	...	...
Mixed forage						
Leaves and grasses[99] ...	...	7·0	2·0	5·5	5·0	2·2
Cereal grass[76] ...	26·9	...	...	5·9	...	0·9
Cereal grass clippings to simulate grazing[77] ...	23·8	...	...	8·5	...	0·8
Cereal grass protein, extracted[79] ...	60·0-100·0	1·0-2·0	...	1·2-2·6	3·5-5·2	0·7-1·2
Cocksfoot and Timothy grass protein, extracted[79]	55·6-85·0	1·4-2·3	...	1·8-2·7	3·1-4·4	0·8-2·3

ACIDS							Method of estimation
Phenyl-alanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
...	1·2	1·8	...	...	...	...	C
...	...	...	...	...	...	...	CC
...	...	...	...	...	...	...	CC
...	1·7	2·6	...	...	...	...	C
...	...	...	...	...	...	...	CC
...	1·9	2·7	...	...	...	...	C
...	2·2	2·5	...	...	...	...	C
...	1·8	2·5	...	...	...	...	C
...	0·5	...	...	...	...	...	C
5-6	2·0	2·5	5·4	10·0	5·0	5·0	MM
4·1	...	1·2	7·5	8·5	5·7	5·3	...
4·8	...	1·6	4·8	6·7	5·8	5·9	...
3·2-5·5	...	...	4·1-6·3	...	...	5·8-9·0	CC
3·8-4·5	...	...	3·5-4·1	...	...	8·0-9·5	CC

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CHAPTER XII

ALGAE

Fresh Water Algae

The use of fresh water algae as photosynthetic agents was first reported by Harder and Witsch[1], but to Spoehr and Milner[2,3] we owe the concept that these unicellular organisms can be considered as a source of food. This concept is based on the fact that algae are capable of building up high concentrations of organic matter from inorganic compounds[2,4]. Sun light being the preferred source of energy for this synthesis[3,5,6], algal culture is pre-eminently suited to the tropical regions of the world[7], especially those with a high percentage of clear days[5]. The main advantage claimed for algal culture is the higher yield of products of photosynthesis over that obtained with conventional forms of agriculture[5,7,8-10]. As such, the potentialities of algae as a source of human food would be especially high in the over-populated areas where the pressure on the land is great[8,11,12] and may well be a means of averting famines which frequently recur in these areas[2]. Waste land not suited to other purposes can be used for the culture of algae[5,8], which does not, therefore, interfere with the raising of normal agricultural crops[8].

Of special importance is the discovery that among the very many species of fresh water algae, the culture of one in particular viz., *Chlorella pyrenoidosa*, can be controlled so as to influence the composition of the algae at the time of harvest[2,3-5,10,13-16]. By suitable variation of some of the cultural conditions, it has been possible to obtain a final product with as high a protein content as 50 per cent or as high a fat content as 75 per cent[2,3]. Chlorella may thus be regarded as an efficient converter of light energy into chemical energy in the form of products, the nature of which can be controlled at will to a considerable extent[4].

Cultural conditions: These comprise physical conditions such as temperature[3-5,7,15-17], intensity of illumination[4,5,7,8,13,15,16,18,19] and agitation[7], as well as concentration of nutrients like carbon dioxide[4,5,7,15-17], mineral salts[4,5,15-17] and fixed nitrogen in the medium[4,5,10,15,16]. Among these, temperature, agitation and concentration of carbon dioxide and inorganic nutrients affect the yield but not the composition of the algae. A temperature of 20-25°C[3,4,7,16,17], adequate agitation[7] and a concentration of 5 per cent carbon dioxide[4,5,15-17] in the gas stream and of 0.5-0.6M mineral salts[4,15,16] in the medium favour rapid growth of Chlorella and thereby high yields. By treatment of *Chlorella vulgaris* with camphor, a mutant is reported to have been obtained having double the cell size but the same generation

time as the parent strain and thus growing in weight twice as rapidly[20].

Intensity of illumination is reported to have an effect both on the rate of growth[5, 7, 16] and the composition[13, 15, 19] of Chlorella. While the optimal intensity from the point of view of high yields is of the order of 2500-3500 foot candles[16], good growth has been obtained at 1300 foot candles[7] and fair growth even at 500-1000 foot candles[16]. High light intensities do not favour high rates of photosynthesis[4, 8, 18], or induce high protein content[15,19] even under conditions which are otherwise optimal for protein synthesis by the alga. Since the phase of maximum photosynthetic activity is also that of maximum protein synthesis, the most efficient use of Chlorella as a photosynthetic agent lies in protein production rather than in fat production[4].

Cultural conditions which affect mainly the composition of Chlorella are, age of the culture[4, 13, 21] and concentration of fixed nitrogen in the medium[4, 5, 10, 15, 16]. Protein content of the cells of *Chlorella vulgaris* has been reported to decrease with increasing age[21]. High concentrations of fixed nitrogen in the medium favour high rates of protein synthesis[4, 5, 10, 15, 16]. A concentration of fixed nitrogen of 0.001 M is critical in this context and if sufficient precautions are taken to see that its concentration never falls below this level, Chlorella rich in protein can be harvested[4, 5, 15, 16]. The availability of different forms of fixed nitrogen to Chlorella has been investigated in detail[22]. Chlorella is capable of utilising nitrate nitrogen[22], but organic and inorganic ammonium salts[7, 22] and urea[17] are superior as sources of fixed nitrogen. It has been suggested that it would be profitable to use sewage as the nitrogen source in algal culture[4, 23]. The use of algae in space ships to convert the waste products of the passengers into the much needed edible proteins and fats has also been envisaged[8,24].

Protein content: Cultured under conditions optimum for protein synthesis, Chlorella attains a protein content of 50 per cent[2, 5, 7, 8, 10, 14, 15, 25], equalling the best vegetable sources[8, 10, 14] and surpassed only by a few animal sources[14]. It has been reported that 33 per cent of the total nitrogen of the alga, *Elodea canadensis*, is contributed by non-protein constituents such as amides, polypeptides and free amino acids[26].

Amino acid composition: The earliest report on the amino acid composition of Chlorella protein is by Eny[27] to the effect that it lacks in essential amino acids other than leucine, isoleucine and valine, but Fowden[28] found all the essential amino acids in the Chlorella protein hydrolysate. Published values on the amino acid composition of Chlorella suggest a fairly good spectrum of the essential amino acids, except for a deficiency in cystine[21, 29-31] and methionine[14, 23, 30-32]. Chlorella protein is particularly rich in arginine[21, 29], lysine[21, 29, 31] and threonine[21, 29-33]. The essential amino acid index of Chlorella

protein is calculated to be 62 according to Oser's formula[34], compared to 100 for whole egg protein, 80-90 for animal proteins and 60-80 for cereal proteins[14]. In the general pattern of distribution of essential amino acids, Chlorella proteins show many similarities to yeast porteins, and, barring its lower cystine content, to leaf proteins[29]. Age of culture is reported to have little effect on the composition of the proteins of *Chlorella vulgaris*, except for a significant increase in the histidine content with increasing age of cells[21].

Digestibility: Little information is available on the digestibility of Chlorella proteins. However, the proteins of other species of fresh water algae like *Myriophyllum* and *Vallisneria* are reported to possess very low digestibilities in rats[35]. The proteins of *Elodea* have a digestibility of only 70 per cent[35], and of *Scenedesmus obliquus*, a digestibility of only 61 per cent[36]. It is difficult to explain these low digestibilities in view of the fact that these algae[35], like Chlorella[8, 13] itself, have a low fibre content.

Nutritive value: Among algae other than Chlorella, while the proteins of *Elodea* have a biological value of 42 per cent, those of *Myriophyllum* and *Vallisneria* have biological values too low to be accurately determined[35]. On the other hand, the proteins of *Scenedesmus obliquus* are reported to promote the same rate of growth in rats as milk proteins and not to cause liver necrosis, unlike fungal proteins[36].

The first animal experiments with dried Chlorella carried out in 1949 at the Stanford Research Institute showed that rats fed diets containing 18 per cent Chlorella protein grew at one-third the rate of rats fed diets containing the same proportion of casein[14]. In a subsequent experiment carried out in England in 1951, Henry[37] found that the protein efficiency ratio of Chlorella is of the same order as that of brewer's yeast, being significantly higher than that of groundnut meal but considerably lower than that of dried skim milk[6, 7, 14]. In experiments with chicks, it was found that substitution of 10 per cent Chlorella in place of an equal quantity of soya bean meal had an adverse effect on their growth, mainly on account of a lowered food consumption[32]. The hygroscopic nature of dried Chlorella is reported to interfere with the ingestion of sufficient quantities of the experimental diets by rats[14] and chicks[32].

Supplementary Value: The proteins of *Scenedesmus obliquus*[33] and *Chlorella pyrenoidosa*[31, 33] have been reported to supplement the proteins of wheat flour and white bread. This supplementary effect is attributed to the high content of threonine and, to a lesser extent, lysine in the algal proteins[31, 33]. In view of the fact that threonine, unlike lysine, remains expensive[31, 33], it has been suggested that algae can be used as a natural source of threonine in supplementing lysine-enriched white bread[31].

Large scale culture and yield: Attempts in the United States[8, 23], Germany[8,25] and Japan[23] at large scale culture of algae brought to the fore many attendant chemical engineering problems and these have been since investigated in detail[38, 39]. Among these problems, the first is to provide the means for the algae to grow at the maximum rate continuously and the second, to harvest the mature algae exclusively, leaving behind the growing young algae[8]. Other problems which await solution are pH stabilisation[38], disposal of toxic products[38] and above all, methods of circumventing light saturation[8]. Provided the intensity of illumination is not too high, the efficiency of light energy conversion in large scale cultures of Chlorella is reported to be of the order of 12-20 per cent[18].

The economics of Chlorella production is still a subject of speculation[3, 10]. On a conservative estimate, Milner[5] concludes from the results of laboratory scale experiments that 40 tons of Chlorella can be obtained annually from an acre of land, whereas other estimates for the annual yield of Chlorella in tons per acre lie as far apart as 2.85 tons[3, 4] and 114 tons[8]. An extrapolation of pilot plant results would suggest that an annual yield of 17.5 tons of Chlorella per acre is quite a reasonable expectation with the present technological knowledge[8, 9]. The fact that the maximum yield reported in laboratory scale cultures is over five times the best yield obtained in the pilot plant gives rise to the hope that a great increase in yield during large scale culture of algae may be realized, once we have a better understanding of the optimum conditions for growth on a large scale[8]. Conditions which contribute to maximum yields of *Chlorella pyrenoidosa* in mass culture have been investigated[40].

Utilisation as human food: The flavour of dried Chlorella is too strong for one to enjoy eating large quantities of it[14]. It has a vegetable-like flavour[8, 14], not unlike that of raw lima beans or raw pumpkin[8]. Its flavour is reported to be also reminiscent of green tea or seaweed[41]. Consumption of fresh Chlorella leaves behind a lingering, mildly unpleasant aftertaste[14]. An effort is necessary to learn how to cook Chlorella or otherwise process it as human food[8].

Large scale trials with Chlorella as human food have yet to be put through. Work carried out in Japan has shown that considerable amounts of Chlorella can be added to green tea, soups, noodles, baked products and ice cream without materially affecting their taste and appearance[41]. An attempt at extracting a 'tofu'-like material from Chlorella failed, but by hydrolysis of the alga, a solution was obtained which could be used as a substitute for soya sauce[41].

Marine Algae

The enormous and self-replenishing supplies (200-300 million tons) of marine algae in the oceans of the world have not yet been fully

exploited directly as source of human food[42]. The common classification of marine algae is by colour; brown (*Phaeophyceae*), red (*Rhodophyceae*), green (*Chlorophyceae*) and blue-green (*Myxophyceae*); only the more prolific brown and red algae offer economic possibilites as food[43, 44].

SEAWEEDS: From early times, man has attempted to utilise seaweeds as food[43, 45]. Considerable quantities are consumed in the oriental countries[43, 44], headed by Japan with 25 per cent seaweed in her dietary[43]. In Europe and America, seaweeds are mainly used as appetisers or stabilisers of food[43]. Britain's seaweed resources are fully listed and the possibility of mechanically harvesting seaweeds from the sea bed is being explored[46].

It has been realised only recently that different species of seaweeds show considerable seasonal variation in chemical composition and that, just as with land crops, there are optimal seasons for harvesting[46]. To make the best use of seaweed as food, it should, therefore, be harvested when the nutritive principles are at their maximum concentration[44].

Protein content: The normal range for the protein content of seaweeds is 4 to 18 per cent on dry weight basis [44, 46-57], but a range of values between 23 and 33 per cent has also been reported[58-64]. In general, the red algae have a higher protein content[61-64]; *Porphyra tenera*, for example, is reported to have a protein content of 33.1 per cent[61]. Among the protein-rich green algae, mention may be made of *Ulva pertusa* or sea lettuce (31.5 per cent)[60] and *Entermorpha flexuosa* (26.4 per cent)[58].

Considerable seasonal variation in the protein content of marine algae has been observed[44, 54-57, 59, 65-67]. While most seaweeds show a clear maximum in the spring[54-57, 63, 66] when the growth of plants is very active[66], with some the protein content is highest in autumn[65] and with others, in winter[59].

Seaweed protein can be extracted with 0.5N to 1N sodium chloride or sodium hydroxide solution[60]. Protein is present to some extent at least as an alginate complex[63] and this is believed to interfere with the protein extraction[53, 68]. Though appreciable quantities of free amino acids are present in seaweeds[67], the bulk of the NPN fraction is chiefly peptide in nature[62, 69]; in this respect, seaweeds differ from fresh water algae[69].

Amino acid composition: The early work of Mazur and Clarke[47, 70] showed that amino acids absent were different with different species of seaweeds. Thus, according to them, *Fucus*, *Egregria* and *Cystoseira* lack arginine, but *Caulerpa* lacks lysine[70]. While *Sargassum* and *Chondrus* lack methionine, *Laminaria* lacks, in addition, lysine and *Ulva*, tyrosine and lysine[47]. Recent work using more modern techniques has, however, shown that such wide qualitative differences in the amino acid composition of the proteins of different species of marine algae do

not exist[42,62,68,71,72] and that except for the absence of certain amino acids like tryptophan[67,71] and methionine[73] in a few isolated cases, they contain all the essential amino acids[74].

In amino acid composition, marine algae essentially resemble the fresh water algae[53] and the land plants[43,53,67,71]. The proteins of different brown[51,62,67,75] and red[62,75] algae show the same amino acid pattern. While *Chondrus crispus*[75] has a very high arginine content, *Rhodymenia palmata*[75] and *Fucus vesiculosus*[67] have high lysine contents. The cystine content of brown seaweeds is reported to be higher than that of the red seaweeds[74]. Seaweed proteins are, as a class, deficient in methionine[67,75,76]. Proteins of dried algae are deficient in histidine[68,74].

Digestibility: Seaweed proteins have a low digestibility as compared to animal proteins[43,44]. The proteins in certain species are reported to be almost completely indigestible[65,77,78] and to lead to loss of protein from the accompanying feeds[65,77]. It is believed that certain substances appearing in the laminarin-rich extract are responsible for this low digestibility[59]. Recent work carried out in Russia on human beings has shown that assimilation of the proteins of brown algae varies from 32-80 per cent[43,50], while according to Japanese investigators, it ranges from 15-73 per cent[61,79]. Digestibility trials with animals have shown that sublittoral seaweed is more digestible than the littoral[46]. Also, a seasonal variation in the digestibility of the proteins of seaweeds has been observed; while the October samples of sublittoral seaweeds have a negative digestibility for protein, the January samples have a positive digestibility[46].

Nutritive value: In general ,seaweed proteins are not extensively utilised in metabolism[45,48]. Proteins of the red edible alga (*Prophyra tenera*) are reported to possess a higher nutritive value than those of the green alga, *Ulva pertusa* (sea lettuce)[60]. In experiments designed to determine the extent of utilisation of the proteins of different seaweeds by rats, Bender *et al.*[63] found the net protein utilisation (NPU) of the red alga, *Rhodymenia palmata*, to be 42, which is of the same order as that of peas and maize. Experiments with the brown seaweeds were complicated by the fact that they were not palatable to the rats[63]. While the NPU of *Laminaria cloustoni* is 28, that of the other two is negligbly low[63]. Owing to retention of excessively large quantities of water by the experimental animals, the protein efficiency ratios could not be calculated[63].

Supplementary value: In its supplementary value to typical polished rice diets consumed in Japan, green seaweed as a whole is reported to be superior to a number of other foods like soya bean and sesame seeds, but to what extent the protein moiety of the seaweed is responsible for the supplementary value is a matter for conjecture[80].

Utilisation as human food: Seaweed is essentially a supplementary food[45, 46] which can be fed only up to a percentage of the basal diet[45]. Limited quantities of red seaweeds, particularly *Porphyra*[43] and *Rhodymenia* (dulse)[44] are consumed in the United Kingdom. *Porphyra laciniata* is an important constituent of 'Laverbread', the national dish of South Wales[43, 44]. As a class, red seaweeds are relatively more palatable[63] and nutritious[60, 63] and would be a useful source of dietary protein if it were possible to collect it exclusively, unaccompanied by other types[63].

In Japan, the brown seaweeds are incorporated in the flour and consumed in the form of noodles[43]. A Japanese patent exists on the production of macaroni products incorporating seaweed[81]. Its use for the production of yeast has been explored in the same country using strains of *Candida* with a high capacity for assimilating mannitol[68, 82]

Phytoplankton

The large marine algae or seaweeds constitute only one per cent of the total marine vegetation[83]. The greater part of oceanic plant life consists of microscopic phytoplankton (mainly diatoms and dinoflagellates)—the products of extensive marine photosynthesis[83, 84] which form the ultimate food for all the sea fish[83-87]. Phytoplankton has not so far been used as human food to any appreciable extent[87], though the possibilities in this direction have been considered by a number of workers [84, 86, 88]. The rationale underlying the direct consumption of phytoplankton by man is essentially similar to the one which has given fillip to recent attempts at the extraction of leaf proteins for incorporation in human diets. The food chain that leads from the phytoplankton through the zooplankton, and small fish to the large marine fish is a long and wasteful one, for, the food value is diminished approximately nine-tenths after each eating[83, 84]. It is believed that each pound of sea fish represents about 100,000 pounds of phytoplankton, photosynthesised in the oceans of the world[83, 84].

Phytoplankton contains 49 per cent protein on the dry weight basis[85]. It is reported to form an important constituent of certain dishes consumed in winter by the lower income groups along the north coast of China[89], while plankton soup is well known in Venezuela[90]. In case its adaptability as human food on a large scale is established [91, 92], it is reckoned that it would be possible to harvest at least half the oceanic phytoplankton resources without in any way affecting the rate of fish propagation[85]. However, plankton is too highly dispersed[93] in sea water to be economically harvested and mechanical difficulties in the way of its large scale collection will have to be overcome[85, 89, 93] in the first instance.

TABLE XXIV

NUTRITIVE VALUE OF ALGAL PROTEINS

SOURCE	Protein content: N × 6.25 %	Level of feeding %	Nutritive Value: Biological value %	Nutritive Value: Coefficient of true digestibility %	Nutritive Value: Protein efficiency ratio
Fresh Water Algae					
Chlorella (freeze dried)[37] ...	50·0	8	...	...	1·8
Elodea[35] ...	...	...	42·0	70·0§	...
Myriophyllum and Vallisneria[35] ...	...	...	*	*	...
Scenedesmus obliquus[36] ...	...	...	...	60·8	...
Marine Algae					
Seaweeds (different species)[79] ...	...	...	...	15·1-71·5	...
Brown algae					
Ascophyllum nodosum[63] ...	8·8-12·7	10	3·0†	...	...
Laminaria sp[50] ...	4·0-10·8	...	...	31·7-80·0	...
Laminaria cloustoni[63] ...	6·4	5	30·0†	...	...
Laminaria japonica[61] ...	7·3	...	...	57·0‡	...
Pelvetia canaliculata[63] ...	12·7	5	0·0†	...	...
Red Algae					
Porphyra tenera[61] ...	33·1	...	...	72·6‡	...
Rhodymenia palmata[63] ...	23·5-27·5	10	42·0†	...	...

* very low

‡ determined by human metabolism experiments.

† denotes net protein utilisation (Biological value × coefficient of true digestibility.)

§ denotes coefficient of apparent digestibility.

TABLE XXV. **AMINO ACID COMPOSITION**

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Fresh Water Algae						
Chlorella pyrenoidosa[30] ...	43·3	6·1	2·0	5·1	1·8	1·2
Chlorella pyrenoidosa (laboratory sample)[32] ...	40.0	6·0	1·6	6·1	...	1·0
Chlorella pyrenoidosa (pilot plant sample)[32] ...	44.0	4·7	1·4	4·7	...	1·8
Chlorella vulgaris[29] ...	26·9	7·9	1·9	8·5	5·8	2·5
Chlorella vulgaris (5 days old)[21] ...	36·3	8·8	2·1	6·9	5·4	2·5
Chlorella vulgaris (9 days old)[21] ...	24·4	8·0	2·4	6·9	5·4	2·5
Chlorella vulgaris (21 days old)[21] ...	23·8	8·3	2·9	7·4	5·8	2·3
Chlorella vulgaris (35 days old)[21] ...	23·1	7·0	3·5	7·6	5·6	2·1
Chlorella vulgaris (Emerson strain)[30] ...	40·9	3·8	1·4	2·2	3·2	1·1
Marine Algae						
Brown algae						
Ascophyllum nodosum (alcohol-extracted)[75] ...	14·4	4·0	0·8	4·1	1·9	†
Ascophyllum nodosum protein, extracted[53] ...	41·0	5·9	0·0	3·4	1·0	†
Cystoseira[70] ...	...	0·0	2·6	3·4	1·9	0·9
Egregria[70] ...	...	0·0	2·4	0·3	1·4	1·1
Fucus[70] ...	...	0·0	0·6	6·0	1·7	0·6
Fucus vesiculosus (alcohol-extracted)[75] ...	17·1	4·1	0·9	5·0	2·5	†
Fucus vesiculosus (alcohol-extracted)[67] ...	14·8-17·5	4·7	0·9	5·0	2·5	...
Laminaria[47] ...	3·6	8·0	0·9	0·0	3·9	1·3
Laminaria cloustoni protein, extracted[53] ...	34·2	6·1	0·0	3·8	1·9	†
Lessoniopsus[70] ...	...	1·6	0·7	6·4	1.2	2·2
Macrocystis[70] ...	...	4·4	0·9	1·6	0·6	0·6
Pelvetia canaliculata[62] ...	10·8	...	...	...	2·8	...
Sargassum[47] ...	6·2	4·0	1·9	4·4	2·9	1·8
Green algae						
Caulerpa[70] ...	...	3·0	1·8	0·0	2·7	2·2
Codium[70] ...	...	3·6	2·7	4·4	1·0	0·5

† denotes weak ninhydrin colour.

* (C: Chemical; CC: Chromatographic;

ACIDS							Method of estimation*
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
5·0	0·8	0·5	4·3	8·7	5·3	5·7	M
5·4	...	1·4	4·8	5·0	4·2	6·7	M
4·1	...	0·8	4·8	8·6	4·0	5·6	M
5·3	0·3	2·4	3·9	9·2	5·3	7·4	CC
4·3	0·2	2·4	4·1	9·2	4·7	7·5	CC
4·3	0·3	2·4	4·8	8·4	5·1	7·0	CC
4·3	0·3	2·2	4·8	8·4	4·8	7·2	CC
4·1	0·3	2·0	3·7	9·0	5·3	7·9	CC
11·6	0·6	1·0	2·3	8·4	5·9	5·3	M
4·3	†	1·2	3·8	6·9	4·2	5·0	CC
...	†	...	3·7	...	...	...	CC
...	3·0	10·5	...	...	...	...	C
...	0·8	4·3	...	...	...	...	C
...	2·2	9·4	...	...	...	...	C
4·9	†	0·7	4·5	7·5	4·5	5·2	CC
4·9	†	0·7	4·5	7·5	4·5	4·0	CC
1·9	4·7	0·0	...	3·8	...	6·8	C
2·1	†	...	4·2	...	...	...	CC
...	1·5	5·8	...	...	...	...	C
...	0·8	28·9	...	...	...	...	C
...	...	...	...	2·3	2·6	2·8	CC
0·6	4·0	0·0	...	0·5	...	8·6	C
...	0·8	2·7	...	...	...	...	C
...	0·7	3·9	...	...	...	...	C

M: Microbiological).

TABLE XXV. *Amino Acid Composition*

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Enteromorpha intestinalis protein, extracted[53] ...	...	4·2	0·5	3·1	2·5	†
Ulva, specimen I[47] ...	11·9	3·7	0·7	0·0	0·0	0·4
Ulva, specimen II[47] ...	11·1	...	...	0·0	0·0	0·7
Ulva lactuca (alcohol-extracted)[75] ...	20·8	5·0	0·5	4·8	3·3	†
Ulva lactuca[94] ...	...	...	...	...	2·7	1·2
Ulva pertusa (sea lettuce)[60]	31·5	...	...	...	4·9-18·8	0·2-0·9
Blue-green alga						
Gliotrichia[70] ...	...	1·3	0·9	1·7	1·9	0·4
Red algae						
Chondrus[47] ...	6·4	5·1	1·1	3·3	4·8	1·9
Chondrus crispus (alcohol-extracted)[75] ...	27·3	14.0	0·6	2·8	2·1	†
Rhodymenia palmata[62] ...	24·4	...	...	...	3·0	...
Rhodymenia palmata (alcohol-extracted)[75] ...	13·0	5·4	0·6	5·3	3·3	†
Rhodymenia palmata protein, extracted[53] ...	...	2·9	0·6	3·3	2·7	†

† denotes weak ninhydrin colour.

ACIDS							Method of Estimation
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
3·9	†	...	2·7	...	...	...	CC
4·3	2·5	0·0	...	7·8	...	7·0	C
...	2·9	0·0	...	...	...	...	C
5·6	†	1·7	5·7	7·5	4·2	6·6	CC
...	3·0	2·0	...	...	...	...	...
...	...	...	...	...	...	...	...
...	0·0	24·3	...	...	...	...	C
2·8	2·2	0·0	...	8·0	...	3·8	C
2·4	†	0·9	2·7	3·9	2·6	3·5	CC
...	...	...	...	2·9	2·7	3·0	CC
5·8	†	1·0	5·3	6·9	4·7	5·8	CC
2·3	†	...	2·9	...	...	...	...

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CHAPTER XIII

YEASTS, MOLDS AND BACTERIA

MICROORGANISMS are associated with human nutrition in its several aspects[1-7]. They are present and they function in the human gut[2-6]. Such fermentative processes as are involved in the preparation of food are mediated by them[2, 6, 7]. Among microorganisms capable of elaborating proteins fit for human consumption[1, 2, 8], yeasts, molds (fungi) and bacteria merit consideration in that order[1].

YEASTS

Yeast is capable of synthesising protein from simple compounds[9-18] in the shortest time[1, 9, 17, 19, 20]. Conditions favouring yeast growth have been studied by several investigators[11, 12, 14] and it has been reported that under optimum conditions yeast can double its weight in less than two hours[20]. The efficiency of conversion of carbohydrate into protein (in the presence of nitrogen supplements) is stated to be of the order of 16-33 per cent in the case of yeast[10, 13, 21, 24], but only 5 per cent in the case of an animal such as the pig[24]. Yeast thus provides an excellent means utilising industrial wastes for producing protein, and bye-products such as molasses[1, 9, 11, 12, 14, 17, 25-28], skim milk[29], whey[23, 29-35], fruit wastes[21, 26], groundnut protein waste liquor[36], potato starch waste liquor[27, 37, 38], sulphite waste liquor from paper pulp manufacture[14, 39-42] and materials like bracken[14], bananas[14, 26, 27], carob beans[27], (*Ceratonia siliqua*), wood[1, 16, 22, 27, 41, 42], straw[27, 42], seaweeds[43, 44], putrefied fish[45] and even sewage[15].

The practical use of yeast in human diets dates back to the first world-war when Germany produced considerable quantities (nearly 20,000 tons per annum[9]), chiefly from wood hydrolysates[9, 18, 19, 46]. The second world war revived interest in yeast as a source both of dietary proteins and of vitamins[42] and the annual production in Germany shot up to 100,000 tons[28, 46]. Besides primary grown yeast, large quantities of brewer's yeast also are obtained as a bye-product of the fermentation industries[18, 19, 46]; but, in spite of facile methods for debittering being available[46], the bulk of the brewer's yeast is wasted for lack of market[28, 47, 48]. The potentialities of yeast as a source of protein in the dietary, especially of under-developed countries, have been generally recognised[14, 17, 28, 49]. On a rough estimate, it has been calculated that three million tons of yeast would be required annually to meet the needs of the 1,000 millions inhabiting these countries[2]. However, consumption of yeast by man has not extended as fast and as much as was first anticipated.

Of the two main species of yeast used for food production, namely *Torula utilis* (mineral yeast)[6, 9, 10, 12, 14-17, 19, 21-23, 25, 33, 38, 40, 42-46] and *Saccharomyces cerevisiae*[12, 13, 16, 21-23, 46], the former possesses the following advantages over the latter: (*i*) it is less bitter[53]; (*ii*) it can tolerate high temperatures as prevail in the tropics[16, 19, 25]; (*iii*) it can grow exclusively on inorganic nitrogen[19]; (*iv*) it can utilise pentoses as are present in straw hydrolysates and in the still bottoms obtained from alcoholic fermentation of wood sugars[42]; and (*v*) its cell size can be suitably increased by mutation, thereby facilitating its production on a large scale[14, 26]. A new *Torula* strain, *Torulopsis utilis* var. *Thermophile*, has been shown to be capable of multiplying fifteen-fold in nine hours[19, 25]. Dried Torula yeast has a light yellow colour with a nutty or meaty flavour and can be used as food yeast[14, 19].

Protein content: The crude protein content of most edible samples of yeast ranges from 40 per cent to 60 per cent[13, 14, 16, 17, 19, 21, 22, 26-28, 30, 31, 38, 41, 46, 54-77], but that of some 'fat yeasts' is considerably less[78-80]. A high concentration of nitrogen in the medium favours synthesis of yeast with a high nitrogen content[80, 81]. The true protein content of yeast has been reported to vary from 30 per cent to 43 per cent on the dry weight basis, as judged from six samples[82]. On an average, only about 80 per cent of the total nitrogen in yeast is true protein nitrogen[83], while from 10 per cent to 20 per cent [71-75, 78, 84] or more [75, 82] is contributed by non-protein constituents, chiefly purines[2, 13, 19, 46, 73, 74, 76, 79, 82, 84-87], pyrimidines [13, 19, 46, 73, 82, 84] and amino acids[2]. Purines account for 5.7 per cent to 13.9 per cent of the total nitrogen [2, 77, 82, 85-87]; pyrimidines, 2.9 per cent to 4.3 per cent [82, 86]; choline, 0.5 per cent[86] and glucosamine, 0.5 per cent[86]. Since the nitrogen content of these constituents also get included while determining total nitrogen in yeast, the true protein content of yeasts would be appreciably lower than the figures quoted for their crude protein contents in the literature[19, 46].

The proteins of yeast include albumins, globulins, phosphoproteins, nucleoproteins, lecithoproteins and glycoproteins, together with the usual soluble protein cleavage products[1]. Attempts to isolate and characterise yeast proteins have not proved very successful[19]. It is reported that only a portion of the nitrogen can be extracted from yeast even by dilute alkali after defatting or rupturing the cell membrane[88].

Amino acid composition: The amino acid composition of yeast proteins is presented in Table XXVII. It is not as constant as that of animal proteins[19], for, it is influenced not only by the strain of yeast[46, 61, 68, 75, 81], but also by the condition of its propagation[61, 76, 80, 89, 90].

On the whole, yeast proteins are well balanced in respect of all the essential amino acids[19, 69, 91-94], except methionine[19, 53, 58, 62, 68-70, 77, 78, 81, 88, 90, 93] and possibly cystine [19, 62, 73, 75, 77, 81, 86, 88, 89, 92, 95, 96]. For this reason, fortification of yeast with materials (such as keratins) rich

in the sulphur amino acids has been advocated[97-99]. Methionine deficiency is reported to be greater in the proteins of *Torula utilis* than in those of *Saccharomyces cerevisiae*[58, 68, 81]. The concentration of methionine in the medium influences the methionine content of yeast proteins only in the case of certain strains[81, 90]. Supplementation with methionine improves the nutritive value of yeast proteins[16, 56, 68, 73, 84, 100], but whether supplementation with cystine has a similar effect is a point of controversy[56, 63, 73, 84, 98, 99, 101].

The presence in yeast proteins of considerable quantities of lysine[53, 57, 61, 62, 70, 75, 78, 86, 89, 90, 93, 95, 102] and valine[53, 57, 58, 61, 70, 75, 86, 89, 90, 93] makes it an ideal supplement to cereal diets in general and wheat diets in particular[57].

The relative availability of essential amino acids from yeast proteins has been measured, using as criterion the extent of their liberation after digestion with pancreatin for 24 hours; the availability varies from 26.7 per cent for histidine to 100 per cent for cystine, while the values for the other essential amino acids lie in between[62].

Nutritive value: Yeast proteins are reported to be highly digestible[31, 98], both *in vitro*[83, 92] and *in vivo*[18, 59, 62, 68, 71, 74, 76, 78, 103, 105]. The nutritive value of yeast proteins is a rather controversial subject[46, 75, 92]. Conflicting reports[28] are found in the literature; some have held yeast proteins to be high class[14, 18, 28, 59, 63, 76, 103, 106, 107], while others have condemned them on grounds of possessing a very low nutritive value[55, 100, 108-111]. The truth perhaps lies between these two extreme views. The majority of literature data would point to the conclusion that yeast proteins are of medium biological value[62, 67, 68, 71, 77, 78, 112-116] on a par with other plant proteins[23, 73, 104, 117], but definitely inferior to proteins of animal origin[16, 19, 56, 62, 73, 84, 98, 104, 117-119], unless supplemented with cystine[112] or methionine[16, 68]. The nutritive value of yeast proteins is influenced not only by the species[16, 68, 71, 110, 112] and strain[68, 111] of the yeast, but also by the speed and conditions of its propagation[112] and the composition of the culture medium[59, 71]. While the proteins of *Torula utilis* are reported to be inferior both in growth-promoting value[16, 68, 110] and biological value[68, 71, 110, 112] to those of *Saccharomyces cerevisiae*, proteins in baker's strains are inferior to those in brewer's strains in growth-promoting value[68, 111], but not in biological value[68]. Addition to the culture medium of extractives from bye-products of corn products and malting operations has a favourable effect on the nutritive value of yeast proteins[59].

Processing: While the nutritive value of yeast proteins is reported to be increased on autolysis[118], the effect of heat processing is a subject of controversy[100, 113, 120].

Supplementary value: As a protein food, the importance of yeast arises mainly from its supplementary value[46, 75], particularly to

diets in which bulk of the protein is derived from cereals[2, 46, 52, 119]. In practice, yeast is, therefore, intended to be essentially a supplement[2, 28] and not as the chief source of protein in any dietary[28, 46, 75, 81]. Up to half the animal proteins can be replaced by yeast proteins in different diets, without appreciably lowering the overall nutritive value of the mixed proteins[81, 121, 122].

Yeast possesses a moderate supplementary value to the poor rice diet[54, 123] and the poor jowar diet[54] and a good supplementary value to poor vegetarian diets based on ragi[54] and milo[54]. As supplement to the poor European diet[119], yeast is reported to be as good as dried milk, meat and fish, while its supplementary value to the Puerto Rican rural diet is even greater than that of skim milk[124].

Supplementary relationships have been shown to exist between the proteins of yeast and those of wheat[28, 64, 67, 78, 116, 125-128] (including wheat gluten[55]) and wheat products[57, 129], corn[14, 28, 62, 64, 74, 126-130], rice[28, 116, 126, 127], oats[127], jowar[116], ragi[116], soya bean[73] and blood[55]. While yeast proteins are superior to groundnut proteins[64] in supplementing wheat proteins, it is a point of controversy as to whether they are also superior to soya bean proteins[64, 129] in this respect. They are on a par with casein[74] and the proteins of non-fat milk solids[64], (sweet cream) butter milk[64] and soya beans[64, 129], but superior to corn gluten[129] and groundnut proteins[64] in supplementing corn proteins. Improvement in the nutritive value of the proteins in certain wheat and corn products has been shown to be only slight, unless the level of supplementation with yeast exceeds 3 per cent[129].

Utilisation: Food yeast is a pale yellow product[14, 19, 26, 60] with a pleasant alcoholic odour[14] and a nutty or meaty taste[19, 26]. Debittered[46, 131-133] brewer's yeast is reported to possess a bland flavour[131]. Yeast has been claimed by German workers to have special value in promoting a feeling of satisfaction or satiety in persons on a poor diet[2]. It has been incorporated in leavened[2, 14, 15, 25, 26, 48, 57, 119, 131-137] and unleavened[138] bread, biscuits[2, 14, 25, 26, 119, 126, 127, 131, 133], doughnuts[135, 136], soups[2, 14, 25, 26, 40, 41, 60, 107, 126, 127, 131, 133, 134, 136, 137], stews[14, 25, 26, 60, 107, 126, 135], gravies[2, 107, 126, 127, 137], porridge[119], meat products[60, 107, 126, 127, 133, 135-137], cheese[131, 133, 135], peanut butter[126, 127, 131, 135-137], paste goods[60, 127, 129, 133, 139], candies[131, 133, 137], cooked cereals[127], dhal[138], cooked vegetables[107, 138, 140], curries[141] and curry powders[2]. Up to 3 per cent of yeast can be used in the preparation of most of these foods and food adjuncts without any deleterious effect on their quality[2, 60, 119, 126, 127, 132, 133]; in fact, its inclusion is reported to actually improve the taste of some of them[60]. On storage, however, a few of the yeast-fortified products develop bitterness and unpalatable flavours[133]. As much as 20 per cent of yeast can be added to peanut butter without any detectable change in its taste[127]. Bread lends itself to fortification with yeast at levels up to 3 per cent[2, 119, 127, 132],

but there are contradictary reports as to whether higher levels of fortification are feasible [2, 119, 132]. Although macaroni, as such, is not a good carrier for yeast, incorporation of yeast at levels up to 7 per cent is rendered possible by the use of highly seasoned foods in the preparation of dishes based on the fortified macaroni products [139].

Toxicity and ill-effects: Brewer's yeast[26], particularly the viable specimens[63] in the live condition[142], is reported to be capable of causing intestinal upsets [137, 143]. On the other hand, food yeast is comparatively innocuous[26].

Diets containing some yeasts as the chief source of protein are reported to cause necrosis of the liver in experimental animals [101, 109, 144-147], which, in most cases, leads to their ultimate death [98, 99, 101, 144]. Other yeasts, however, do not cause necrosis [56, 73, 148, 149]. Cystine [65, 99, 101, 144], methionine [145] and vitamin E [65, 146] are reported to have a protective effect. Different yeasts have different necrogenic property, depending on the level of protein in the diet [56, 73, 78], on the species or strain of the yeast[73, 78] and on the medium of its propagation [146]. In general, yeasts of European origin [65, 111, 147] and baker's strains[111, 147] are reported to be more necrogenic than those of American [65, 111, 147] and Indian [148] origin and brewer's strains [111, 147]. It is a moot point whether the variations in their toxicity is entirely due to the differences in their sulphur amino acid contents [61, 65, 111].

Since yeast is rich in purines and nucleoproteins, its ingestion influences both uric acid accumulation and excretion in the human body [19, 46]. The question as to whether the consumption of yeast will give rise to abnormal quantities of uric acid and consequent disorder is of considerable importance[46]. According to some investigators, no rise in the blood uric acid is observed following the administration of yeast, but their experiments have invariably been of short duration or have involved small doses of yeast [134, 150-152]. Ingestion of comparatively large quantities of yeast by human subjects for several days has usually resulted in an increase in the concentration of uric acid in blood[76, 108, 114, 134, 152, 153] and in its excretion in the urine [76, 114]. Concomitantly a rise in the blood creatinine [76], loss of weight [76, 134] and decrease in blood pressure [76] have also been observed. Consumption of 75 g. of dried yeast per day increases the uric acid content of blood by 75 per cent[153] and of 100 g. per day, by 100 per cent [114]. A rise, even two-fold, in the blood uric acid level does not produce symptoms of gout [114]. It is thus not probable that yeast, in the quantities ordinarily consumed, would cause an increase in the production of uric acid sufficiently high as to exert a harmful effect on the human system or to lead to the formation of uric acid stones[46]. However, a thorough study of the effects of prolonged ingestion of large quantities of yeast on the blood constituents and general well-being is a desirable pre-requisite for any recommendation concerning the inclusion of yeast as a major

source of protein in human dietaries[19]. Suggestions have also been made for the removal of the greater part of the purines from yeast before use[76, 164].

Human tolerance for yeast: The limits of human tolerance for yeast as reported by different investigators vary widely[114, 119, 134, 138, 155-160], from one-fourth ounce per day[119, 155] to as much as three ounces three times daily[160]. Consumer acceptability trials carried out in India have shown that half an ounce of food yeast is the optimal daily allowance[138, 159].

Economics of yeast production: The economics of yeast production has been the subject of extensive study[14, 22-25, 27, 38, 41, 46, 52, 161]. While yeast protein is cheaper than animal proteins[23, 27, 41, 46, 52] (with the exception of skim milk protein[46]), it is considerably costlier than proteins of plant origin[22, 23, 46]. The relatively high cost of yeast protein is reported to be the main reason for the slow development of the food yeast industry in the United States[53]. The future of yeast as a source of protein in human diets may not be bright unless it can compete in price with cheap protein-rich foods like soya bean and groundnut flour[161]. Various improvements have been suggested in the process of yeast manufacture with a view to reducing the production costs[38].

DISTILLERS' BYE-PRODUCTS: Distillers' bye-products are the residues obtained in the manufacture of alcohol and distilled liquors from cereal mash after the removal of alcohol[162]. Their production increased rapidly after the outbreak of the second world war[62, 162] and the present annual output is estimated at over 300,000 tons[162, 163]. They have recently assumed considerable importance as an ingredient in commercial feeds for poultry and farm animals[62, 163] and they also deserve consideration as a protein supplement in human diets[62].

In the recovery of distillers' bye-products, the total solids of the spent wash are concentrated and dried together to give distillers' grains with solubles[162, 163] ('dark grains'[162]). Alternatively, the soluble and insoluble solids may be dried separately to give respectively distillers' dried grains ('light grains'[162]) and distillers' dried solubles[162, 163]. The yield of the total bye-products per bushel of grain mixture is usually 16.5—17.0 pounds, divided almost equally between dried grains and dried solubles[162]. The composition of all these products varies widely, depending on the type and proportion of cereal grains constituting the mash[62, 162], the composition of these grains[62, 162], the efficiency of fermentation[162] and the proportional content of yeast in the final product[62]. While distillers' dried grains are reported to be similar in composition to palm kernel cake, dried solubles (which contain the bulk of the soluble nutrients derived from the cereals and yeast[62, 162, 164, 165]) are similar to dried milk[163]. Ordinarily, 20 per cent by weight

of the solids in dried solubles is contributed by yeast[162]. The protein contents of dried grains, of dried grains with solubles and of dried solubles are reported to be respectively 30 per cent[162], 29 per cent [162] and 26.0-37.1 per cent [62, 162].

The proteins of distillers' dried grains resemble cereal proteins in amino acid composition[165]. The proteins of dried solubles are richer than cereal proteins in arginine [165], histidine[165], lysine [69, 165] and tryptophan[69], presumably as a result of the preferential synthesis of these amino acids by yeast during the course of fermentation[165]. Lysine has been found by animal feeding experiments to be the primary deficiency and tryptophan, to be the secondary deficiency in the proteins of the dried solubles, thereby showing that adequate quantities of these amino acids are not contributed by the yeast normally present therein[62]. The availability of these two amino acids from the proteins of dried solubles is also of a lower order than their availability from yeast proteins[62]. As a source of methionine, the proteins of dried solubles compare favourably with casein[162].

The proteins of dried solubles are inferior in nutritive value to casein, yeast proteins and even corn proteins[62]. The importance of dried solubles in nutrition arises mainly from its supplementary value[166]. Because of its high methionine content, the proteins of dried solubles would be a valuable supplement to soya bean proteins[162]. They also supplement yeast proteins, but their supplementary value to corn proteins is not considerable unless fortified with yeast in sufficient quantities to make good their deficiency in lysine and tryptophan[62]. Thus, apart from its beneficial effect on protein content and palatability[164], increasing the yeast content of distillers' dried solubles by suitable fermentation methods is desirable, also from the nutritional point of view[62].

The preparation of protein hydrolysates from spent brewers' grains by digestion with 10 per cent hydrochloric acid has been reported[167].

Molds (Fungi)

Like yeasts, molds too, particularly members of the genera *Aspergillus*[168] and *Penicillium*[168], are capable of synthesising proteins from inorganic salts as the sole source of nitrogen[168, 169]. But, while molds have been used on a large scale in obtaining fats from carbohydrate, their use for the production of proteins has not received much attention, primarily due to their inferiority in this respect to yeasts, especially *Torula utilis*[1]. However, as many molds are capable of breaking down celluloses and hemicelluloses, their employment to produce protein from mixtures of fibrous materials and inorganic nitrogenous salts offers considerable possibilities[1]. Thus, as a result of growing a non-pathogenic strain of *Aspergillus fumigatus* on straw impregnated with ammonium salts, the protein content of the mixture has been

reported to increase from 1 per cent to 8 per cent[170]. Mold (*Oidium lactis*) mycelium protein has also been obtained by the biosyn process using whey as substrate[171].

In general, the protein content of molds is less than that of yeasts and bacteria[58]. It varies with species[168], media[158, 168] and conditions of propagation[58, 178], from 13.7 per cent to 62.5 per cent[1, 58, 168, 171-173] on dry weight basis. Mold mycelium contains nearly 50 per cent more protein before sporulation than after[58, 174]. The isolation of an alkali-soluble protein resembling leaf protein in composition, from *Penicillium chrysogenum* has been reported[175]. Nearly one-third of the total nitrogen in molds is non-protein[173].

The amino acid composition of mold proteins also varies with species [58, 173], medium[58], aeration[58] and age of cells[58, 174]. Mold proteins are rich in histidine[58] and, in some cases, also in lysine[174]. They are very deficient in methionine[58, 174] and tryptophan[174]; in fact, the latter amino acid is totally absent in old cultures of *Aspergillus flavus*[174]. *Penicillum notatum* is richer in most of the essential amino acids (particularly histidine) than *Rhizophus nigricans* and *Aspergillus niger*[58]. The histidine content of the mycelial protein increases after sporulation and the mycelium contains three times as much histidine as the spores[58]. Supplementation with cystine improves the nutritive value of certain mold proteins[169], but not of others[168, 176], presumably due to a species difference in their cystine contents[168, 169]. In fact, the proteins of *Aspergillus flavus* are quite rich in cystine[174].

The digestibility of the proteins of *Aspergillus oryzae*[176] is quite high, in contrast to that of the proteins of *Penicillium notatum*[172]. The biological value of mold proteins is also highly variable[112, 168, 172, 176,] depending on the species and the speed and conditions of propagation[112]. None of the molds is toxic[169, 172]. The mycelial proteins of *Penicillium notatum*, obtained as a residue from penicillin factories, possess a fairly high biological value[172]. The proteins of *Aspergillus sydowi* are supplemented to a considerable extent by casein and the proteins of whole wheat, corn gluten feed, skim milk, egg white and yeast, and to a slight extent, by soya bean proteins[168]. Gelatin has no supplementary value to the mold protein[168].

Edible Fungi: Edible fungi among which the French cepe[177] (*Boletus edulis*) is the most highly valued species, are consumed in large quantities in different regions like Tierra del Fuego, New Guinea, Asia Minor and Germany[178]. In countries with severe winters when vegetables become scarce, fungi, collected in autumn and dried or pickled in brine[178], are consumed instead.

Edible fungi contain 1.0 per cent to 4.8 per cent digestible protein on the fresh weight basis[179]. Cooked fungi are reported to be more nutritious than most cooked vegetables[177] and the fungal proteins, only slightly inferior to meat proteins in nutritive value[179].

MUSHROOMS: Considerable quantities of mushrooms are cultivated in the United States and Canada[180]. It is estimated that over 40 million pounds of mushrooms are produced annually in the former country[180]. *Agaricus campestris* is the common commercial species[180].

The literature on the protein content of mushrooms shows great divergence[178, 180]. At one extreme, they have been claimed to be an adequate meat substitute[178, 180, 182]. At the opposite extreme, Chatfield and Adams[181] have assigned a value of zero for the protein content of mushrooms. Evidently, both these are exaggerations[178, 180, 186]. The protein content of different varieties of mushrooms ranges from 1.3 per cent to 7.2 per cent on the fresh weight basis[178, 180, 182-184] and from 32.5 per cent to 49.1 per cent on the dry weight basis[183, 185-187]. Of the total nitrogen, 31 per cent to 37 per cent is non-protein[184, 188]. Purified mushroom protein has a rather low nitrogen content (11.79 per cent)[184].

Mushroom protein is a rich source of methionine, isoleucine and valine, but is very poor in tryptophan[184]. In fact, tryptophan is reported to be totally absent in certain mushrooms[189]. The greatest concentration of amino acids is found in the stem of the mushroom, the next greatest, on top of the umbrella and the lowest, underneath the umbrella[189].

The digestibility of the proteins in different varieties of mushrooms varies from 45.4 per cent to 84.0 per cent[178, 188, 190, 191]. The nutritive value of mushroom protein is far less than that of casein[180, 184] and considerably less than that of soya bean protein[184]. The soluble proteins of mushrooms possess a higher nutritive value than the insoluble moiety[192]. It has been found that for the maintenance of an adult in nitrogen equilibrium with mushrooms as the sole source of dietary protein, from 43 to 62 g. of the nitrogenous extractives are required daily, corresponding to 100 to 200 g. of dried mushrooms[191].

The possibilities of growing mushroom mycelia in submerged culture, after the methods employed in the antibiotic industries, have recently been investigated in detail, especially in respect of *Agaricus campestris*[185, 186] and *Agaricus blazei*[187] (the latter, using citrus press-water as substrate). The flavour of mushroom can be varied to a considerable extent by changing the conditions of fermentation[186]. It can be processed by techniques commonly used for vegetables, like canning, freezing or dehydration[186]. Processed mushroom has been used in soups[185, 186], sauces[186], gravies[185], spaghetti[186] and meat dishes[186].

BACTERIA

Autotrophic bacteria[1] are capable of synthesising their cell proteins entirely from inorganic nitrogen[169, 193]. Certain cellulose fermenting bacteria[1, 194] (*Coryne-bacterium*[195] and *Cellulomonus* sp.[195]) can fix nitrogen acting symbiotically with the autotrophic organisms. The use of bacteria as a possible commercial source of protein has the

following limitations: (*i*) one is not certain of their freedom from pathogenicity[1]; (*ii*) they produce obnoxious materials like indole, skatole, butyric acid etc.[1]; (*iii*) turnover rate of proteins by bacteria (especially soil or water borne, the ones most likely to be useful) is very slow, being of the order of several weeks in contrast to the few hours in the case of yeasts[1]; and (*iv*) protein yields are also quite low as compared to yeasts[194]. Although bacteria of the type of *azotobacter* are of great value in fixing organic nitrogen in soils[1], their use as a direct source of dietary protein appears doubtful, unless the speed of synthesis[1, 195] and yields[195] are considerably improved.

The protein content of bacteria differs with species[58], varying from 24.7 per cent to 82.4 per cent[58, 196, 198, 199]. *Escherichia coli* is a particularly rich source of protein (82.4 per cent)[58]. Different strains of *azotobacter* have protein content ranging from 24.7 per cent to 61.2 per cent[196].

It is a moot point as to whether species makes a difference to the amino acid composition of bacterial proteins[58, 102, 197]. According to Stokes and Gunness[58], proteins of *E. coli* are richer in most of the essential amino acids than those of *Bacillus subtilis* and *Staphylococcus aureus*. Bacterial proteins are, as a class, rich in isoleucine[58]. The proteins of *S. aureus* are particularly rich in lysine[58] and those of (butyl) fermentation residue, in methionine[199]. The gram positive cocci are reported to contain only about half as much arginine as the gram negative bacteria[102, 197]. The amino acid composition of the proteins of *Lactobacilli*[197], *E. coli*[102, 197], *B. subtilis*[58] and *Aerobacter aerogenes*[102] is not affected by the composition of the medium, while the presence or absence of glucose in the medium makes a considerable difference to the content of some of the essential amino acids in the proteins of *Streptomyces griseus*[58].

Bacterium coli, killed by heating at 80° C for 1 hour, is reported to be quantitatively equal to fish meal as a protein supplement for young rats[198]. The innocuity of the suspension of *B. coli* has been shown in experiments with more than 600 animals fed with it[198]. The ability of *B. coli* protein to promote growth is reported to be even greater than that of the conventional animal proteins[198]. However, the possibility of using bacteria as a direct source of protein in human dietaries still remains to be determined by careful experimentation.

TABLE XXVI

NUTRITIVE VALUE OF YEAST, MOLD AND BACTERIAL PROTEINS

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological value %	Nutritive Value: Coefficient of true digestibility %	Nutritive Value: Protein efficiency ratio
Yeasts					
Yeast[103] ...	...	5	85.5	77.0	...
Yeast, dried, raw[113] ...	...	...	45.0†	72.0	...
Yeast, dried, cooked[113] ...	...	...	37.9†	62.0	...
Yeast, protein (grown on molasses)[114] ...	...	...	70.9*	...	...
Baker's yeast, No. 51 (*Saccharomyces cerevisiae*)[68]	47.3	8	58.9	80.7	...
		18	...	...	1.4
Baker's yeast, dried[67] ...	45.6	8	...	...	1.5
		10	...	...	1.3
		12	...	...	1.4
Brewer's yeast (*Saccharomyces cerevisiae*)[112] ...	...	...	84.0†	...	...
Brewer's yeast, commercial[73] ...	44.0	13	...	...	0.5
Brewer's yeast, dried (Fleichmann type 2019)[71]	50.8	8	69.3	85.5	...
Brewer's yeast, dried (Fleichmann's irradiated dry yeast)[62] ...	48.8	10	61.0	83.0	...
Brewer's yeast, No. 52 (Fleichmann's stock)[68]...	47.7	8	58.4	79.9	...
		18	...	...	1.7
Brewer's yeast, non-fermentable, strain K[59]	49.8	5	66.0	91.0	...
		8	66.0	88.0	...
Food yeast (*Torula utilis*)[77]	38.0; 43.7	...	63.0-66.0	...	...
Food yeast[116] ...	52.1	5	...	...	1.2
		8	...	...	1.8
		10	...	...	1.7
Food yeast, No. 1084[68] ...	55.4	8	31.8	84.8	...
		18	...	...	0.9
Food yeast, No. 1084, English origin[71] ...	49.3	8	48.8	88.3	...
Food yeast, No. 3, Puerto Rican origin[71] ...	50.7	8	45.3	87.3	...
Food (*Torula*) yeast[56] ...	53.3	...	...	...	0.8-1.0
Food (*Torula*) yeast, grown on beechwood sulphur waste liquor[112] ...	...	...	34.0†	...	...
Food (*Torula*) yeast, grown on straw hydrolysate[112]...	...	...	64.0†	...	...

† reckoned on the scale, milk protein = 100.

* determined by human metabolism experiments.

TABLE XXVI. *Nutritive Value of Yeast, Mold and Bacterial Proteins*

SOURCE	Protein content: N×6.25 %	Level of feeding %	Nutritive Value: Biological Value %	Nutritive Value: Coefficient of true digestibility %	Nutritive Value: Protein efficiency ratio
Food (*Torula*) yeast, grown on wood sugar[112] ...	...	...	33·0†	...	...
Food (*Torula*) yeast, grown on black strap molasses[73]	53·2	13 21	... ...	... ...	0·6-0·7 0·8
Food yeast, dried (*Torulopsis lipofera*)[78] ...	36·6	12	...	...	0·9
Food yeast, cultured, non-fermentable, strain G[59]...	44·8	5 8	70·0 68·0	91·0 96·0	... ...
Food yeast, cultured, non-fermentable, strain 90[59] ...	47·9	5 8 10	86·0 82·0 76·0	92·0 91·0 87·0	... ...
Food yeast, cultured, non-fermentable, strain 200[59] ...	45·4	5 8 10	89.0 79·0 73·0	91·0 88·0 88·0	... ...
Food yeast, cultured, non-fermentable, strain 300[59] ...	51·8	5 8	72·0 73·0	92·0 88·0	... ...
Food yeast, dried, low in purines[115] ...	...	...	52·0*	...	...
"Kitchen food" yeast[104] ...	...	...	87·0*	87·0*	...
Distillers' dried solubles[62]	37·1	10	53·0	84·0	...
Molds					
Biosyn[112] ...	...	...	53·0†	...	...
Mushroom, edible (*Agaricus campestris*)[190]	...	...	...	71·0	...
Mushroom, edible, fresh[184]	2.2 ; 3·5	8 15	... ...	... ...	0·3 0·5
Mushroom (different sp.)[191]	...	...	...	72·0–83·0	...
Mycelia from *Aspergillus oryzae*[112] ...	...	...	44·0†	...	...
Mycelia from *Penicillium notatum*[172]	27·0-31·0	10	59·8	58·0-59·0	...

† reckoned on the scale, milk protein = 100.
* determined by human metabolism experiments.

TABLE XXVII. **AMINO ACID COMPOSITION**

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Yeasts						
Yeast[89] ...	...	5·4	3·1	9·8	6·0	1·5
Yeast[91] ...	...	4·3	2·8	6·4	4·2	1·4
Yeast[200] ...	...	4·3	2·8	7·5	3·6	1·3
Yeast[201] ...	...	4·0-5·0	3·0	7·0-8·0	3·6	1·3
Yeast, average of 8 strains[75]	...	4·3	2·8	7·5	3·6	1·3
Yeast, dried, for human consumption[95] ...	...	5·5	2·6	9·2	5·2	1·1
Yeast, dried, irradiated[69] ...	55·0	4·0	2·2	8·8	1·8	1·1
Yeast, purine-free[93] ...	...	9·0	3·8	9·0	...	1·4
Yeast, autolysed[75] ...	37·1	4·8	2·8	4·9	3·2	1·1
Yeast extract (liquid)[75] ...	...	3·0	2·3	4·0	2·0	0·8
Yeast foam[102] ...	...	4·3	0·8	7·6	2·3	...
Saccharomyces cerevisiae[58] ...	55·9	4·3	4·8	5·5	...	1·1
Saccharomyces cerevisiae, F-53, grown on beet molasses medium[81] ...	31·9	...	...	...	...	...
Saccharomyces cerevisiae, F-53, grown on beet molasses medium with the addition of ammonium salts to the medium[81] ...	42·5-58·1	...	...	...	...	...
Saccharomyces carlsbergensis[102] ...	...	4·3	2·6	5·3	4·4	...
Baker's yeast, D.C.L. (*Saccharomyces cerevisiae*)[61]	46·3	2·5	4·1	6·7	6·2	...
Baker's yeast, strain No. 51[68]	47·3	...	...	...	...	...
Baker's yeast, strain A.M.[75]	49·4	3·5	2·7	7·6	3·6	1·3
Baker's yeast, strain A.M.$_2$[75]	47·5	4·1	3·0	6·9	3·7	1·3
Baker's yeast protein, alkali-soluble[88] ...	...	...	...	...	3·1	1·8
Brewer's yeast (*Saccharomyces cerevisiae*)[70] ...	57·1	4·5	2·1	6·4	...	1·1
Brewer's yeast[86] ...	...	5·0	5·0	10·0	2·0	0·5
Brewer's yeast[94] ...	...	13·1	3·0	7·4	...	1·6
Brewer's yeast, strain No. 52[68] ...	47·7	...	...	...	...	...
Brewer's yeast, strain B_2[75] ...	46·1	3·1	3·1	8·1	3·9	1·3
Brewer's yeast, strain B_3[75] ...	43·9	4·7	3·0	8·1	3·6	1·3
Brewer's yeast, Fleischmann type[61] ...	52·5	5·0	4·1	6·7	4·1	...
Brewer's yeast, dried, defatted[62] ...	51·5	5·0	1·5	6·2	3·5	0·7
Brewer's yeast, strain G_1, debittered[75] ...	52·0	5·2	2·7	6·8	3·5	1·4
Brewer's yeast, strain G_3, debittered[75] ...	48·8	4·3	2·8	7·6	3·6	1·2
Brewer's yeast, strain K, debittered[75] ...	51·8	5·3	3·0	6·7	3·5	1·5
Brewer's yeast (Harris), debittered[92] ...	...	3·1	3·3	7·1	3·8	1·2

* (C: Chemical; CC: Chromatographic;

OF YEAST, MOLD AND BACTERIAL PROTEINS

ACIDS							Method of Estimation*
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
...	2.3	...	...	7.3	5.8	5.7	...
4.1	1.3	...	5.0	13.2	3.4	4.4	MM
4.1	1.0	1.9	5.5	7.4	5.9	5.0	MM
4.5	1.1	2.0	5.5	7.5	6.0	5.8	MM
4.1	1.0	2.7	5.5	7.4	5.9	5.0	MM
...	2.2	...	...	...	...	...	C
4.2	...	1.3	5.1	7.5	6.9	5.5	M
2.2	...	0.8	4.1	5.1	3.8	4.8	M
3.0	1.2	2.1	5.1	6.8	5.5	5.1	MM
3.9	0.8	2.1	2.0	4.4	3.9	4.7	MM
...	...	...	...	...	...	...	C
3.8	...	1.2	4.3	6.8	4.5	5.0	M
...	...	1.7	...	...	...	...	M
...	...	1.0-1.6	...	...	...	...	M
...	...	...	...	...	...	...	C
5.6	...	1.7	1.4	7.5	4.5	9.4	CC
...	...	1.9	...	...	...	...	C
4.5	0.9	2.7	5.6	6.1	5.8	4.7	MM
3.9	1.0	2.8	5.7	8.0	6.2	4.6	MM
...	0.7	...	...	...	...	...	C
4.4	...	1.4	5.1	7.1	4.2	5.4	M
8.0	2.0	...	...	5.0	...	10.0	...
3.6	...	2.3	5.1	7.8	6.0	6.4	MM
...	...	1.4	...	...	...	...	C
4.1	0.9	2.7	6.0	8.1	6.2	5.4	MM
4.2	0.9	2.6	5.3	7.4	5.6	5.9	MM
1.9	...	2.1	1.4	7.5	4.5	9.4	CC
...	0.4	1.1	...	...	...	...	C
4.4	1.0	2.7	5.2	8.5	6.0	4.8	MM
4.0	1.0	2.7	6.0	7.3	5.5	4.6	MM
4.6	0.9	2.8	5.3	7.1	6.0	4.7	MM
4.5	1.2	2.7	5.5	7.3	6.0	5.3	MM

M: Microbiological; MM: Miscellaneous).

SOURCE	Protein content %	AMINO Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Brewer's yeast protein, alkali-soluble[88] ...	...	2·8	trace	4·5	3·9	1·7
Food yeast, No. 1084 (*Torula utilis*)[68] ...	55·3	...	...	...	...	...
Food yeast (*Torulopsis utilis*)[94] ...	...	8·6	2·8	6·8	...	0·8
Food yeast protein[77] ...	43·7	1·1	0·4	1·2	1·3	0·8
Protein from *Torula candida arborea*[77] ...	46·3	1·4	0·4	1·5	1·7	0·8
Kitchen food yeast[75] ...	41·3	4·0	2·3	8·0	3·4	1·2
Kitchen food yeast[94] ...	...	7·0	2·8	6·3	...	3·2
Top yeast, Dutch[102] ...	...	3·9	2·0	6·4	2·9	...
Top yeast, grown on wort[90] ...	...	...	2·5-2·8	6·8-7·1	...	...
Top yeast, grown on artificial medium[90] ...	...	...	2·2-3·4	6·6-8·8	...	...
Distillers' bye-products						
Distillers' dried solubles[62]...	40·4	2·7	1·5	3·5	5·0	0·5
Corn distillers' dried grains[162] ...	33·3	...	...	...	...	...
Corn distillers' dried grains with solubles[162] ...	32·2	...	...	...	...	...
Corn distillers' dried solubles[162] ...	28·4	...	...	...	...	...
Corn grains with solubles[69]	31·9	2·8	2·5	2·2	2·2	0·3
Corn solubles[69] ...	27·5	2·2	2·5	2·5	2·2	0·4
Milo grains with solubles[69]	36·3	3·0	2·8	2·5	2·5	0·8
Rye grains with solubles[69] ...	31·9	3·8	2·2	3·5	1·6	0·9
Rye solubles[69] ...	40·0	3·5	2·0	1·8	1·5	0·5
Wheat grains with solubles[69] ...	33·8	4·1	2·4	3·0	1·8	0·9
Wheat-Milo grains with solubles[69] ...	31·9	3·7	2·5	3·1	2·5	0·9
Wheat-Milo solubles[69] ...	30·6	3·9	2·3	2·6	2·0	0·7
Molds						
Aspergillus flavus protein, 5th day of incubation[174] ...	...	4·8	*	23·4	7·0	...
Aspergillus flavus protein, 30th day of incubation[174]	...	3·4	trace	10·8	7·6	...
Aspergillus niger, whole culture[58] ...	32·6	3·2	2·8	3·2	...	0·8
Aspergillus niger, mycelium, before sporulation[58] ...	47·6	5·5	2·5	5·7	...	1·1
Aspergillus niger, mycelium, after sporulation[58] ...	31·2	4·5	4·9	3·8	...	1·0
Aspergillus niger, spores[58] ...	34·6	3·4	1·6	3·8	...	1·0

* denotes presence.

ACIDS							
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	Method of Estimation
...	0.3	...	...	...	...	...	C
...	...	1.2	...	...	...	...	C
4.6	...	2.6	5.0	8.3	5.5	5.9	MM
1.7	0.3	0.6	1.9	1.4	...	3.5	...
2.4	0.4	0.6	4.3	...	...	...	...
2.9	1.1	2.8	5.1	6.8	5.8	5.4	MM
4.1	...	6.4	4.9	6.8	5.7	5.9	MM
...	...	...	...	...	...	...	C
3.1-3.4	...	1.5	...	6.2-6.4	5.0-5.2	6.4	M
2.9-4.0	...	1.2-3.5	...	5.6-7.0	4.6-5.8	5.1-6.6	M
...	1.0	1.6	...	...	...	...	C
...	...	2.3	...	...	...	...	C
...	...	2.4	...	...	...	...	C
...	...	2.7	...	...	...	...	C
6.6	...	1.6	3.5	7.5	6.3	5.6	M
6.1	...	1.4	3.3	5.1	5.5	5.1	M
5.2	...	1.4	3.0	5.0	2.5	5.8	M
4.4	...	1.3	3.5	6.8	5.0	5.3	M
4.5	...	1.3	3.0	4.8	5.0	5.3	M
5.0	...	1.5	3.6	7.7	5.9	6.2	M
5.6	...	1.6	3.1	11.0	5.6	6.0	M
4.6	...	1.3	3.6	6.2	5.2	4.9	M
2.8	6.7	trace	4.2	6.8	5.2	4.7	CC
2.0	13.3	*	5.6	5.2	3.4	9.4	CC
2.7	...	0.7	3.4	4.5	2.7	3.3	M
3.1	...	1.1	3.5	5.5	3.0	3.8	M
2.5	...	0.7	3.0	4.2	2.2	3.0	M
2.9	...	0.7	3.7	5.1	2.9	3.7	M

TABLE XXVII. *Amino Acid Composition*

SOURCE	Protein content %	AMINO				
		Arginine %	Histidine %	Lysine %	Tyrosine %	Tryptophan %
Mushrooms, fresh (*Agaricus campestris*)[184] ...	3·5	5·8	...	...	...	0·1
Penicillium notatum[58] ...	38·3	3·7	4·4	4·0	...	1·3
Rhizophus nigricans[58] ...	36·3	3·3	2·7	4·4	...	0·7
Bacteria						
Aerobacter aerogenes[102] ...	...	5·2	2·0	5·7	3·0	...
Bacillus brevis[102] ...	...	5·0	1·5	6·6	4·5	...
Bacillus subtilis[58] ...	62·9	3·8	1·4	5·4	...	0·6
Bacillus subtilis[102] ...	...	3·8	1·5	6·3	3·1	...
Escherichia coli[58] ...	82·4	5·2	1·5	5·5	...	1·0
Escherichia coli[102] ...	...	5·2	1·9	6·2	3·0	...
Lactobacillus arabinosus[197] ...	63·0	3·3	1·7	5·2	...	0·5
Lactobacillus casei[197] ...	46·8	3·6	1·9	7·7	...	0·4
Loctobacillus fermenti[197] ...	87·4	4·8	2·4	6·9	...	0·6
Lactobacillus pentosus[197] ...	60·9	3·1	1·5	4·6	...	0·3
Proteus vulgaris[102] ...	...	3·9	2·6	5·3	4·4	...
Staphylococcus aureus[58] ...	67·2	3·4	1·1	7·7	...	0·3
Staphylococcus aureus[102] ...	...	2·4-2·5	0·7-0·8	7·7-8·8	2·2-3·6	...
Streptococcus faecalis[102] ...	...	2·7	1·2	6·4	1·7	...
Streptomyces griseus[58] ...	56·8	5·1	1·5	3·9	...	1·2
Fermentation residue (Butyl)[190] ...	26·4	...	...	...	...	...

ACIDS							Method of Estimation
Phenylalanine %	Cystine %	Methionine %	Threonine %	Leucine %	Isoleucine %	Valine %	
...	...	4·1	...	6·9	13·1	9·3	M
3·0	...	1·0	3·6	5·5	3·2	3·9	M
2·2	...	0·9	2·6	4·0	2·7	3·0	M
...	...	...	...	...	...	...	C
...	...	...	...	...	...	...	C
3·5	...	1·7	3·5	7·6	4·8	5·6	M
...	...	...	...	...	...	...	C
3·3	...	2·1	3·9	7·8	4·6	5·5	M
...	...	...	...	...	...	...	...
2·8	...	1·1	3·8	5·9	5·6	5·2	M
3·5	...	1·1	4·7	6·8	6·2	5·8	M
4·1	...	1·3	4·9	7·5	7·0	6·8	M
2·7	...	1·0	3·3	5·1	4·9	4·6	M
...	...	...	...	...	...	...	C
2·7	...	1·2	3·0	5·1	4·2	3·6	M
...	...	...	...	...	...	...	C
...	...	...	...	...	...	...	C
2·9	...	1·0	4·2	6·7	2·9	6·2	M
...	...	3·7	...	...	...	...	C

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